Face-to-face interactions in augmented reality games

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Abstract

Augmented reality games are increasingly popular. Like other digital games, they can include multiplayer features in the game setting to enhance the gaming experience. However, most multiplayer augmented reality games keep their focus on what objects players are interacting with and how players interact with them. They generally miss one crucial part of multiplayer games, which is integrating the physical interactions between players. This thesis presents a study of players' physical movements in six degrees of freedom and their physical face-to-face interactions using a marker attached to the back of each device. The main goal of the thesis is to identify a design space for face-to-face interactions between players, which could open many new game design possibilities.

The thesis starts by examining the feasibilities of technology that is used in the setting of face-to-face multiplayer augmented reality games by reviewing the potentials and limitations of current augmented reality engines. The movements and interactions of players in six degrees of freedom are identified. In order to develop a game to be used in a practical study, a game design process is introduced through a series of structured workshops. This results in a process to design a face-to-face multiplayer augmented reality game using cards to represent the components of games. Finally, one of the games which is designed during this game design process is developed and play-tested by a number of participants with computing and games expertise.

This study reveals how physical movements and interactions affect players, augmented reality, games, and social scenarios in game. The movements of one player in six degrees of freedom are categorised into six groups which are horizontal transitions (left and right), vertical transitions (up and down), depth transitions (in and out), roll rotations (rotate clockwise and counter clockwise), yaw rotations (tilt left and right), and pitch rotations (tilt up and down). There are 169 possible combinations of interactions. When these interactions are considered in detail, they can be categorised in six types of movements and produce four groups of limitations when practically implemented in an augmented reality game.

The study identifies an intersection area in which face-to-face interactions in augmented reality can be performed, which this thesis defines as the ‘Detectable area’. The study also finds that the human body’s range of motions also defines the possibilities of interactions between two players. This creates an ergonomic range of face-to-face interactions in augmented reality games that can be used further.

These studies reveal the difficulties of performing each movement and interaction in theory and practical experience. Considering the implementations of the interactions to a game mechanic, sizes of detectable area, and scores which participants during studies gave to each movement, this thesis suggests the level of difficulty of the games which each movement and interaction should also be implemented. An implementation of movements and interactions to a suitable level of difficulty will create a better gameplay experience to users.

These suggestions are considered when designing a multiplayer game. It is revealed that social scenarios in the game that can be divided into cooperative and competitive have a significant impact on the game mechanic and face-to-face interactions. It is discovered during the studies that participants find playing the game in a competitive setting more enjoyable than a cooperative one. However, a cooperative setting encourages participants to communicate more with each other. The face-to-face interactions in a cooperative setting are also easier to perform than in the competitive setting. There are also other minor factors which affect the overall gameplay experience such as sizes of space of gameplay and intimacy among players.

Overall, this thesis suggests that face-to-face interactions could be one of the enhancements to multiplayer augmented reality games. They create a better user experience to players. However, the usage of face-to-face interactions in augmented reality games could be further studied in many more aspects of games in the future.

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Chapter 1

Introduction

Augmented reality, introduced in 1992 (Caudell and Mizell, 1992), is a form of digital experience that establishes an illusion that a 'virtual' world has been overlaid upon the 'real' world. Unlike virtual reality that sets out to transport the viewer to a new virtual world, the core idea behind augmented reality is that the viewer believes they have remained in the real world, but that this is now populated with virtual objects with which they can observe and interact (Azuma, 1997). Augmented reality is, therefore, one particular arrangement of more general mixed reality environments in which real worlds and virtual worlds co-exist in various forms (Milgram et al., 1995). Augmented reality is made possible by the convergence of several computing technologies including positioning and sensing, handheld and head-mounted displays, graphics and sound. These technologies are now becoming mainstream. Hence, augmented reality may soon become a feature of our everyday lives.

Proposed applications of augmented reality span in military, medical, office, education, and entertainment domains (van Krevelen and Poelman, 2010). One of the most compelling applications that may help drive the adoption of augmented reality is gaming, as evidenced at the time of writing by the recent widespread public engagement with the augmented reality game Pokémon Go. By overlaying virtual game content on the player's everyday experience, augmented reality promises to transform the gaming experience in multiple ways. It can utilise real world locations, histories, and populations as a rich backdrop for games. It can transform familiar everyday locations into new fictional settings. It can engage players in physical activities and outdoor exploration. Augmented reality games may also introduce new kinds of social play, including face-to-face encounters, which is a particular focus of this thesis.

There have already been many examples of augmented reality games in academic literature, for example, AR-Quake (Thomas et al., 2000), AR Chess (Reitmayr and Schmalstieg, 2001), Human Pacman (Cheok et al., 2004),

Invisible Train (Wagner et al., 2005), MapLens (Morrison et al., 2009), and AR-Tennis (Henrysson, Billinghurst and Ollila, 2005). Many of these demonstrate potential of *multiplayer* augmented reality games. For example, the ability to overlay an existing classic game with an augmented reality setting (Reitmayr and Schmalstieg, 2001), to use objects in the real world as part of social virtual play (Wagner et al., 2005), to provide a better user experience when detecting another player's existence (Henrysson, Billinghurst and Ollila, 2005), to utilise collaborative play and conversation in the real world to progress the game (Morrison et al., 2009), and to drive the spread of a game on a global scale (Ingress, 2012). In particular, Marcus Montola identifies a social expansion of gaming as one of the three key dimensions of so-called 'pervasive games', alongside spatial and temporal expansions (Montola, 2005), which augmented reality games are part of (Nieuwdorp, 2007). There have also recently been examples of professional augmented reality games that reveal the commercial potential of this form of gaming, for example, Ingress (Ingress, 2012) and Pokémon Go (Pokémon GO, 2016). Interestingly, both games feature social game play.

These examples point towards both the potential and feasibilities of augmented reality gaming as a new game format. They also suggest that social play will be an inherent and important feature of such games. However, as we will show in the literature review afterwards, augmented reality games have, by and large, neglected one important form of social interactions to date – support for direct face-to-face interactions among players. By this we mean situations in which players, who have physically encountered one another in the real world, stand around and directly interact with each other. For example, children standing around in a park or school playground and engaging in a series of face-to-face games.

In response, this thesis introduces a novel approach to support face-to-face gameplay among the players of augmented reality games. To peek ahead, the new concept that will be explored is that of using augmented reality to track the relative movements of players' handheld consoles as they point them at one another. This can be achieved (as we explore later) by placing augmented reality markers on the backs of the handheld consoles or tablets so that they can track each other using their integrated cameras and computer vision software. The result is to set up a situation in which players can point their devices at each other and move them around in order to jointly manipulate virtual objects, wrestle, reveal information about each other, or engage in other social game interactions. This thesis further motivates this approach, introduces it in detail, demonstrates its technical feasibilities, uses it as the basis of a new game design and evaluates how this design is experienced by players. The result is a new approach and framework for designing face-to-face interactions in augmented reality games.

1.1 Thesis contributions

This thesis makes several research contributions as part of an overall journey of proposing, demonstrating and evaluating this new approach to face-to-face gameplay in multiplayer augmented reality games.

The journey begins with reviewing relevant literature. This review provides an overview of current multiplayer augmented reality games, especially of player interactions in face-to-face situations. The review clarifies that there is a research gap in the area of supporting direct face-to-face interactions of the kind described above. The knowledge gained from the review does not only benefit the topic of face-to-face augmented reality games, but also contributes to other multiplayer mixed reality games in different situations.

The specific approach of mutually visually tracking handheld devices is then introduced and further unpacked through a series of technical explorations that serve to demonstrate its feasibilities and raise key challenges to be addressed by further research. Augmented reality technologies as part of face-to-face interactions are observed so as to reveal limitations and constraints in both virtual and real environments. At this point, several metaphors are raised to suggest how the new technique might support game mechanics. These early explorations confirm the feasibilities of face-to-face augmented reality games and contribute to further understanding in terms of the viability of the underlying technology.

In order to further explore the possibilities and challenges of face-to-face augmented reality games, a series of design workshops are then conducted. These utilise a structured process to produce designs for various face-to-face augmented reality games across various genres. The workshops suggest future possibilities for implementing face-to-face interactions into augmented reality games in practical circumstances. They also establish a focus for studies for face-to-face augmented reality games for the second half of the thesis. Additionally, the workshops reveal what key interests and concerns for game designers when designing augmented reality games.

The established areas of study are then investigated through a series of playtests involving a prototype game with participants from various disciplines. The study results are analysed and discussed from the perspective of both mixed reality environments and face-to-face interactions. The study results reveal how players interact with each other when they perform face-to-face interactions, how they feel about these interactions, and how augmented reality in this face-to-face form affects the players' experiences and decisions as the game progresses. The resulting knowledge provides more understanding of face-to-face interactions in multiplayer augmented reality games as a resource for researchers in the mixed reality gaming field alongside guidelines for game

designers and developers to implement face-to-face interactions into augmented reality.

1.2 Thesis organisation

This thesis consists of seven chapters in total, including this introduction. It can be divided into two halves. The first half, which comprises Chapters 2 and 3, establishes the concept of face-to-face interactions in multiplayer augmented reality games. This concept is then explored for its feasibilities and challenges in order to ground the studies in the second half of thesis.

Chapter 2 identifies and reviews the literature on multiplayer augmented reality games. The review focuses on exploring the multiplayer augmented reality gaming topic from several key perspectives including reality-virtuality continuum (Milgram et al., 1995), social expansion in pervasive games (Montola, 2005), and the time-space taxonomy (Johansen, 1988). The review identifies an opening in multiplayer augmented reality games which is an interest of face-to-face interactions between the players in those augmented reality games.

The particular approach to face-to-face interactions in augmented reality games of the thesis is fully established in Chapter 3. The limitations and feasibilities of AR technologies to support this are then appraised covering hardware and software technologies in augmented reality, as well as physical limitations in the real world. Within these limitations, the possibilities of face-to-face interactions among players with multiplayer augmented reality games are explored through a series of structured design workshops. The chapter ends by fusing the results of feasibility work and game design workshops to establish the areas of interest for subsequent studies of prototype face-to-face augmented reality games in the second part of the thesis.

This second part, starting from Chapter 4, contains the studies of face-to-face augmented reality games, their findings, and discussion of their results. A series of user experience studies of face-to-face augmented reality games are reported in Chapter 4 and 5. In Chapter 4, the face-to-face interactions are considered solely on vision-based tracking of players' devices, in other words – marker detection. This study focuses on how players react to individual movements and face-to-face interactions in various social scenarios. The studies and opinions of the participants were recorded. The participants were invited to play the game in single player mode, multiplayer mode with cooperative intention, and multiplayer mode with competitive intention. They were interviewed about their experience with the interactions and the game, their opinion about difficulty of the movements and interactions, and the other factors which influence gameplay. While showing the feasibilities of the approach to support gameplay, the study

also revealed a number of interactional ambiguities arising from relative movements between players.

Consequently, a further series of studies are reported in Chapter 5 with additional information from built-in motion sensors taken into consideration in order to avoid the ambiguities from face-to-face relative movements as identified in Chapter 4. The studies are performed similarly to the studies in Chapter 4. The studies focus on the participant's experience and opinions similar to the last chapter.

In Chapter 6, face-to-face interactions in augmented reality games are discussed in general, drawing on the study results and returning to the literature that was reviewed in in Chapter 2. Each aspect is discussed by linking back to the past chapters so as to ground the discussion both in theory and practice. The result of the discussion is to deliver a design framework for implementing a face-to-face augmented reality game for game designers and developers in the future.

Finally, the thesis is concluded in Chapter 7, including identifying areas for further research.

Chapter 2

Literature review

The main interest of this thesis, augmented reality games, was briefly introduced in Chapter 1. In this chapter, augmented reality games topic is going to be further examined to provide an understanding of its current state and explore the openings of the subject. This chapter presents an overview of the characteristics and history of augmented reality games on both academic and commercial aspects. It is followed by a more comprehensive review of multiplayer augmented reality games to analyse and identify their openings. These lead to an introduction of basic ideas of face-to-face augmented reality games which will be further explored in the next chapter. This chapter is the starting point and sets a path for the research topic in further chapters.

2.1 Augmented reality and augmented reality games

This thesis focuses its interest on multiplayer augmented reality games. However, before start exploring such specific topic, the concept of augmented reality games, which is a more general concept and the superset of this topic, should be firstly examined.

Augmented reality games consist of two principal areas which are augmented reality and games as shown in Figure 2-1.

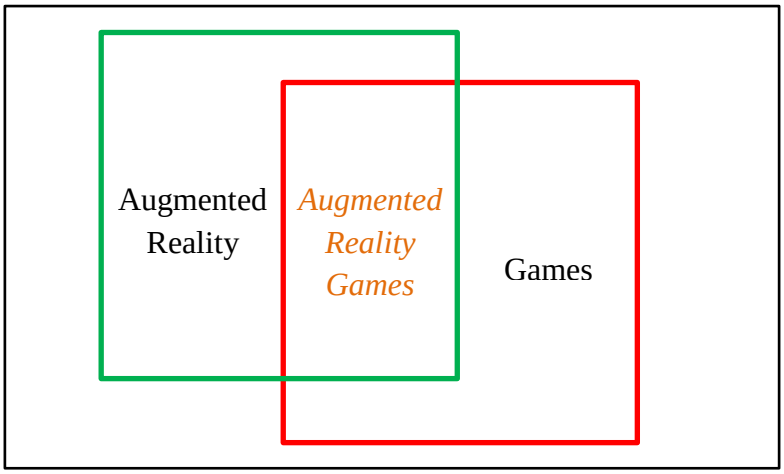


Figure 2-1 Augmented reality games Venn diagram

Augmented reality and games have their own characteristics and properties. They will be investigated separately and then together to define our interest space of augmented reality games.

2.1.1 Augmented reality

Augmented reality (AR) is a form of technology where the real world and the virtual world co-exist. One of general augmented reality definitions is "the supplement of the virtual objects and the reality by superimposing the objects upon or compositing with the real world" (Azuma, 1997). Augmented reality was introduced by Tom Caudell in 1992 (Caudell and Mizell, 1992) to be used in a manufacturing process in an airplane factory (Behringer, Klinker and Mizell, 1999). Augmented reality is defined as a subset of mixed reality which is in between real environment and virtual environment in reality-virtuality continuum (Milgram et al., 1995), as shown in Figure 2-2.

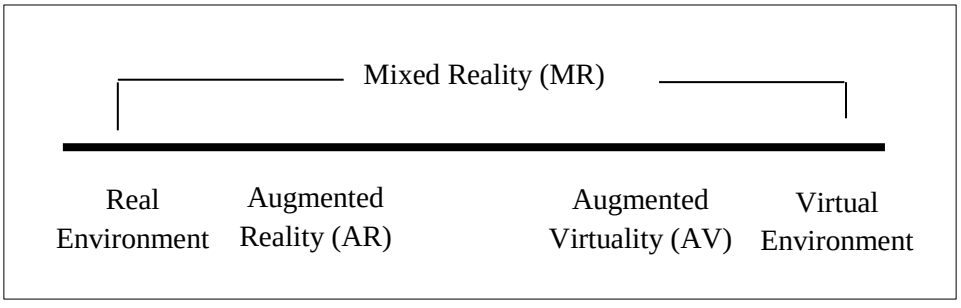


Figure 2-2 Paul Milgram's Reality-Virtuality Continuum (Milgram et al., 1995)

Milgram's reality-virtuality continuum shows the spectrum of mixed reality environment between real environment and virtual environment. However, each

subset of mixed reality is placed at a different place on the continuum showing how close it is to each end of the spectrum. Augmented reality is placed closer to the real environment than the virtual environment. This is because in augmented reality, unlike virtual reality which brings the user fully to virtual environment, the user can see both the virtual world and the real world simultaneously (Azuma, 1997) and objects in both worlds generally appear to be corresponding with each other. This does not mean that the importance of virtuality has been removed or inferior to reality, but instead virtuality is brought into the real environment with equal significance. This is one of essential points of augmented reality technology which is the basis of this thesis further on.

Kato et al. (2000) described the process of vision-based augmented reality which could be adjusted and applied to a general augmented reality process. In general, augmented reality requires three main steps: the real world's reference points detection and identification, virtual objects generations, and scene augmentations as shown in Figure 2-3.

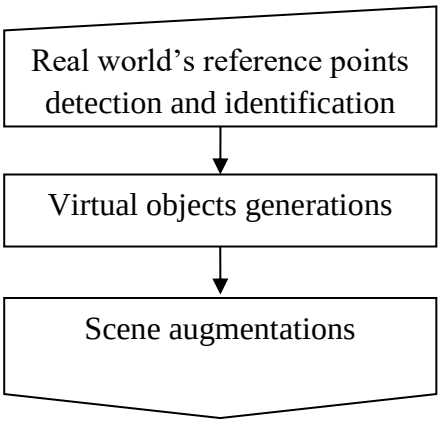


Figure 2-3 General augmented reality process

More precisely, each step contains several sub-steps before the final scene is produced. Firstly, augmented reality starts with detecting reference points in the real world which trigger the augmented reality process to start. These points could be images on video stream, points from GPS, etc. By gathering information in the real world, the information will be processed and sent to generate virtual objects that are appropriate for that real-world information. After that, the virtual objects are augmented back to the real world in appropriate positions and orientations to create the final scene.

Macwilliams et al. (2004) studied several different augmented reality systems and revealed that there is an augmented reality basic architecture structure which consists of common components and subsystems. The six main subsystems of generic augmented reality architecture are shown in Figure 2-4.

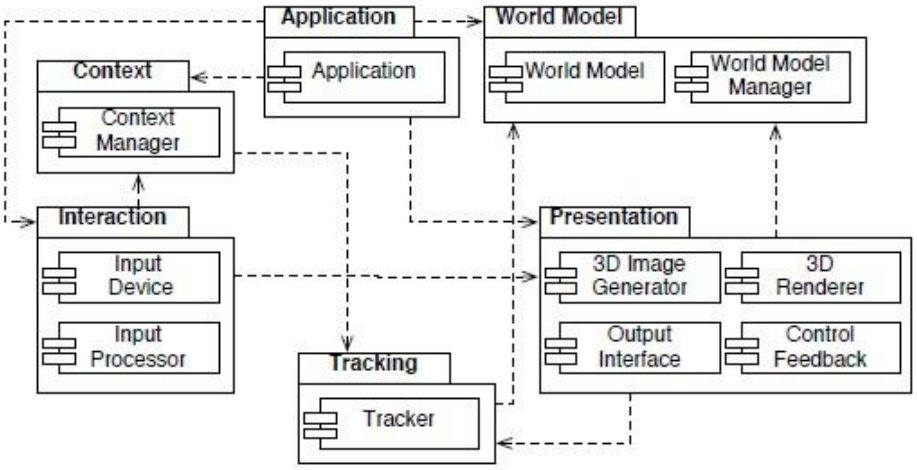


Figure 2-4 Generic augmented reality system reference architecture (Macwilliams et al., 2004)

Six main augmented reality subsystems consist of: Interaction, Tracking, Context, Presentation, World Model, and Application. Each of these subsystems serves different purposes in the whole augmented reality system. Interaction subsystem gathers and processes any input that matters from the user. At the same time, Tracking Subsystem keeps track of the augmented reality reference's pose which is provided in parallel to the other subsystems. It can be at the time of reading an input or providing an output back to the real world. Context subsystem collects the context data and provides it to other subsystems. All data is processed, and Presentation subsystem displays those processed outputs to the user whether they are 2D, 3D, or device feedback. The outputs are posted back to be displayed in the real world by World Model subsystem which collects real world information linked to the real-world objects or the user's position and it could be taken into consideration of the augmented reality system. Overall, Application subsystem bootstraps all functionalities and data of an augmented reality system.

Considering both Milgram's reality-virtuality continuum and Macwilliams' augmented reality architecture, it can be said that even in the augmented reality system itself, its components are placed at various positions on the continuum. The Interaction subsystem is responsible for inputs from the user e.g. a touchscreen, mouse, keyboard, gamepad, etc. This subsystem works more closely to the reality side than the virtuality side. On the other hand, the Presentation subsystem prepares the objects or feedbacks that will be displayed back to the user. Hence, it is also placed closer to the virtuality side. The Tracking and World Model subsystem gather information in the real world. However, they still work on the software side of the system. They should be placed near the reality side but not nearer than the Interaction subsystem. As the Context subsystem works to gather the context data, it is placed closer to the

virtuality side but before the Presentation subsystem. Finally, the Application subsystem works on several levels on the continuum. Therefore, it can be placed anywhere on the continuum. These are shown in Figure 2-5.

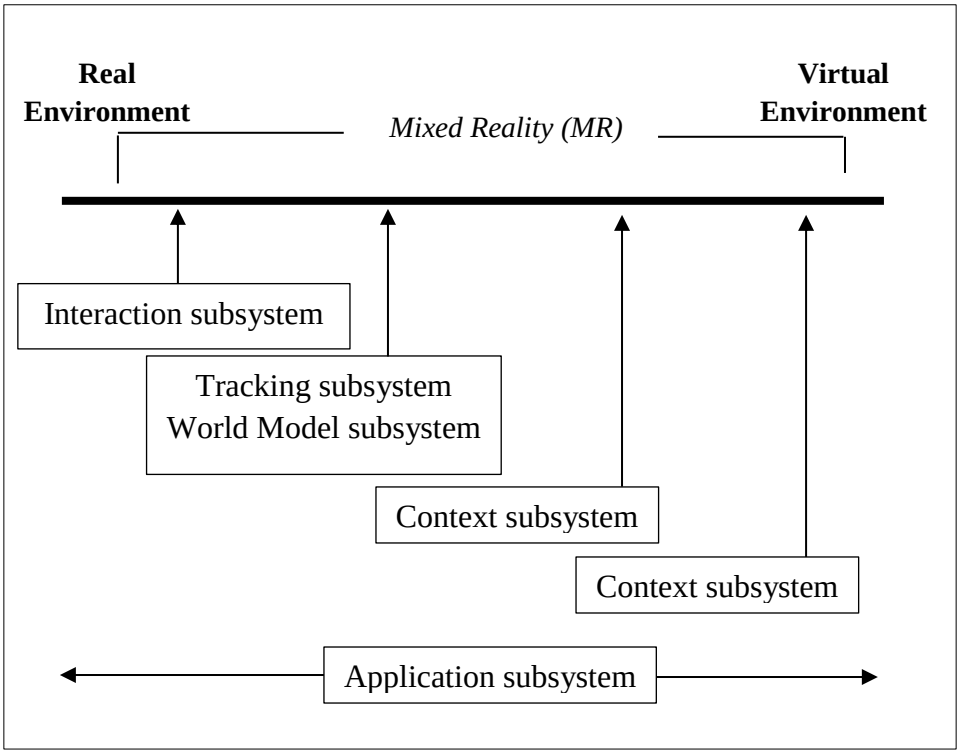


Figure 2-5 Augmented reality basic architecture mapped on Reality-Virtuality Continuum

Looking back through the history of augmented reality technology, the development was limited to the head-mounted display devices in its early days due to the limitations of hardware technology. However, as the supporting technology and the algorithm of augmented reality technology itself have been improved, the development point of view has been widened and led the development into three major devices.

Head-attached displays

Head-attached displays are the original devices of the augmented reality technology which have been used for the longest period. Head-attached displays are the devices that "require the user to wear the display system on his or her head" (Bimber and Raskar, 2005b). They are probably the devices among three kinds of major augmented reality devices that can produce the most realistic scene because they are normally placed near the observers' eyes while in use. However, there are also a few drawbacks. In the past,

most of them were bulky and heavy so they were not suitable for consumer usage. Furthermore, they could not be taken off easily from user's head while using which could cause motion sicknesses when any sudden changes happened (Kolasinski, 1995).

Despite their downsides, head-attached displays have recently been released to general consumers. In the past, head-attached displays were usually used in research labs. There have been attempts to create new devices that are much lighter and smaller in a shape of sunglasses, or even contact lens (Parviz, 2009). They are still in an early stage, but some products have already been introduced, for example, Google Glasses by Google (Google Developers, 2012), Oculus Rift by Oculus VR (Kickstarter, 2012), Playstation VR (Playstation, 2016), HTC Vive (Vive.com, 2017), and Microsoft Hololens (Microsoft HoloLens, 2017). Although some products are not designed for augmented reality directly, they are still useful for augmented reality technology itself. These provide a promising approach to head-attached display devices and augmented reality technology. The product trend has brought head-attached devices to attention and has led to further development of the head-attached display devices in the future.

Spatial displays

There are some scenes of augmented reality that are really overlaid in the real environment. They are implemented to the real world by using any projective devices to a "screen" which can be anything that can receive and reflect light. For instance, a white wall, frosted glass, smoke, including computer screens. One of the early examples was a concert performed entirely by virtual idols from a famous Japanese computer music software called Vocaloid. A big hidden frosted glass was used as a screen projecting a series of pre-rendered animated images of virtual singers and the concert was performed just like real humans in the real performance (Cruz, 2010). Another example was the usage of cheap and small projectors to create impressive and portable augmented reality scenes (Shi, Becker and Riviere, 2012), (Aksit et al., 2013). These examples show that, with the improvements in hardware, augmented reality can be used almost anywhere.

Handheld displays

This kind of augmented reality display is the most well-known and could be considered the most well-balanced between easiness of the development process and realism. Handheld devices such as mobile phones or tablets have already been integrated into our daily life. Therefore, they should be

the most convenient devices for end consumers to experience augmented reality technology (Schmalstieg and Wagner, 2007). The development of this kind of devices emerged from an attempt to reduce the size of the augmented reality system where the technology allowed (Wagner and Schmalstieg, 2006). The examples of this kind of devices could be dated back from the era of PDAs (Wagner et al., 2005) to the present era of smartphones (Madden, 2011).

Normally, the real environment would be read through the devices' camera. After some image processing, the virtual objects would be augmented at the destined position and shown on the screen. All the process would be finished in the devices that can be held in user's hands (Schmalstieg and Wagner, 2007). This convenience enables many augmented reality applications into handheld devices and integrates to the daily usage, e.g. Layar (Layar, 2009), Ingress (Ingress, 2012), Pokémon Go (Pokémon GO, 2016), etc.

These three kinds of augmented reality displays are different in terms of device location between the user's eyes and projected objects, and the position of augmented images which produces different user experiences. These differences of augmented reality displays are shown in Figure 2-6.

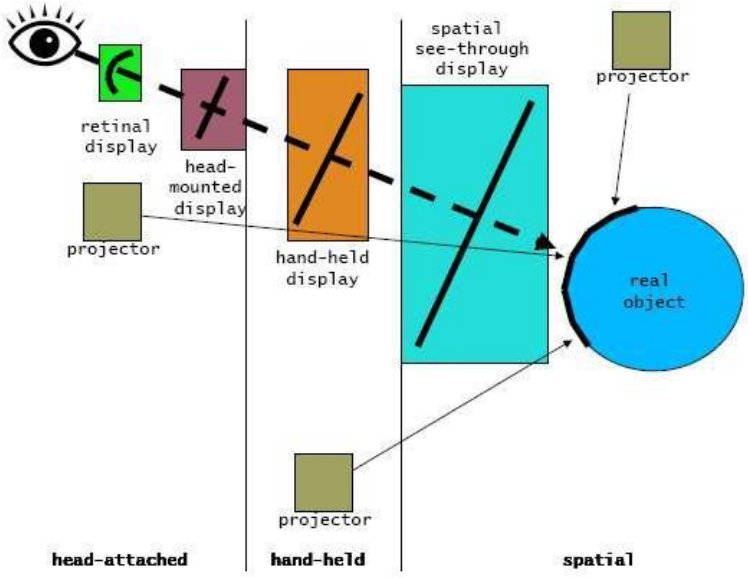


Figure 2-6 Augmented reality device and image locations (Bimber and Raskar, 2005a)

In terms of technology applications, augmented reality is the technology which can be applied to numerous fields of applications. It has a capability to be adapted into many areas (Behringer, Klinker and Mizell, 1999). In the first International Workshop on augmented reality in San Francisco in 1998, there

was a workshop where the question "What will be a killer application of augmented reality?" was posed for a group discussion. The group could not deliver an exact answer of "killer application" but the discussion opened several possibilities of answers to the topic, even though the device technology such as handheld devices were not much developed at that time. It shows that augmented reality has a potential to create applications in many areas since the early days of technology. Van Krevelen and Poelman (2010) surveyed the applications of augmented reality technology and categorised them into six major groups of applications.

1. **Personal information systems**
   Augmented reality possesses an ability to overlay a content or message to the user in the real world. When this ability is combined with personal wearable computing, it can create an "advanced, immediate, and more natural UI for wearable and mobile computing in personal, daily use" (van Krevelen and Poelman, 2010). Examples of this type of augmented reality applications are personal assistance, navigation, touring, etc. which enable any useful information relayed to users.

2. **Industrial and military**
   Augmented reality is useful for design, assembly, and maintenance. It possesses an ability to superimpose information on the real position in the real world. Therefore, it can be used to pilot a design space and direct on how things can be assembled / maintained. These activities are useful for corporate and military settings in both for training and real situations.

3. **Medical**
   Like industrial and military applications, augmented reality can superimpose information on the real position in the real world and can also be used in medical settings. It can be used either for training using a simulation or in the real situation using information from ultrasound, CT, MR scans, etc. overlaying on the real scanned position.

4. **Office**
   Augmented reality can be used in collaboration in office spaces. Using the ability of augmented reality which simulates information and allows user to interact with the information in real-time can be useful for public management, urban planning, etc.

5. **Education and training**
   Augmented reality can be used to support education with 3D objects. Many researchers present educative applications using augmented reality from time to time. Furthermore, augmented reality can also be used to create new forms of visual art.

6. **Entertainment**
   Augmented reality can be used for sports broadcasting by overlaying real-time information on the live stream video to give the audience more perspectives of the game. Augmented reality is also used to enhance the user's experience in games.

Augmented reality in games, which is going to be the focus of this thesis, is part of augmented reality technology in entertainment. Since augmented reality technology was first introduced, many augmented reality games have also continuously been developed. This is because augmented reality can open numerous options of new game mechanics. Combining the usage of augmented reality on several gaming devices such as smart phones, personal computers, or head-mounted displays, it makes games more compelling because the methods of interactive input and the outputs to users can make them feel much more realistic.

2.1.2 Games

Games have a long history in humankind and it is a vast area which engages many fields of knowledge. There are an enormous number of research topics that investigate subdivisions of games. Various attempts have also been made to define what games are.

The definitions of games are determined from many aspects. Suits (2005) defined games as "a voluntary effort to overcome unnecessary obstacles", while Tekinbaş and Zimmerman (2003) defined games as "a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome". However, there is a much simpler definition of games proposed by Rogers (2014) that game is an activity that: -

1. Requires at least one player
2. Has rules
3. Has a win and/or lose condition

He offered an example of a hand ball game. Bouncing a ball and catch it in hand, ball is simply a time-waster activity with only one person, a ball, and a wall. However, when rules and win/lose conditions are added, this activity transforms into a game. Hence, this definition seems to cover every aspect of a game definition. From this definition, it can be interpreted and visualised into a diagram in Figure 2-7.

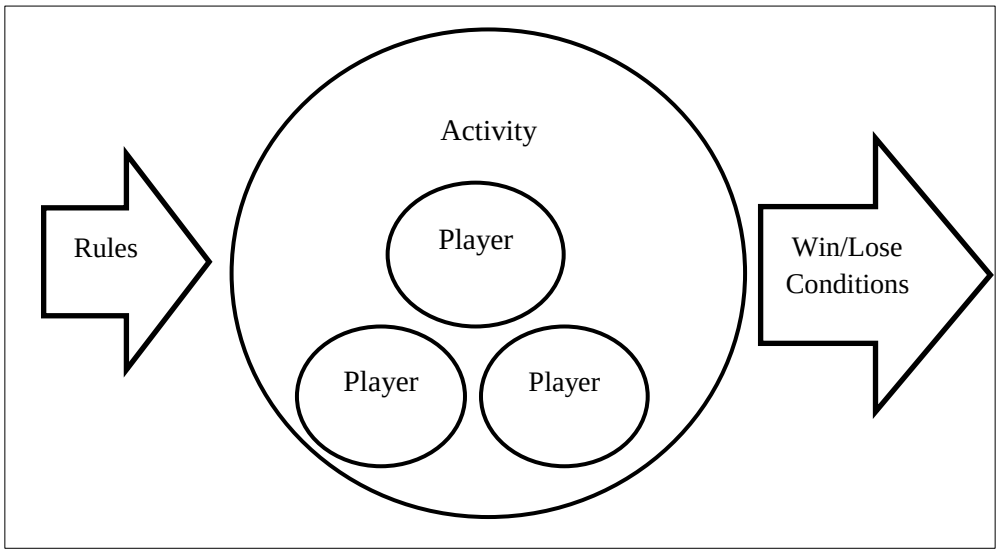


Figure 2-7 Visualisation of definition of games

Video game is a kind of games which has been alongside computer history from the start. One of the first digital video games named ‘Bertie the Brain’ (Kates, 1950) was introduced back in 1950 with extremely simple graphics. Since then, video games have been improved in gameplay, graphics, interactions, sound, and the other countless parts. Video games have become an enormous industry with huge revenue and increasing growth rate. It is reported that the video game market value worldwide was 108.9 billion United States dollars in 2015 and estimated to reach 128.5 billion United States dollars in 2020 (Newzoo, 2017).

Games consist of many complex parts and several layers which are strongly related to each other. Lopes and Kuhnen (2007) proposed a layered view structure to simplify the complexity of the game design cognitive process. They break the game design cognitive process into five layers and two kinds of approach. When consider closely, these five layers of the game design cognitive process are also the breakdown of game layers. The layered view of the game design cognitive process is shown in Figure 2-8.

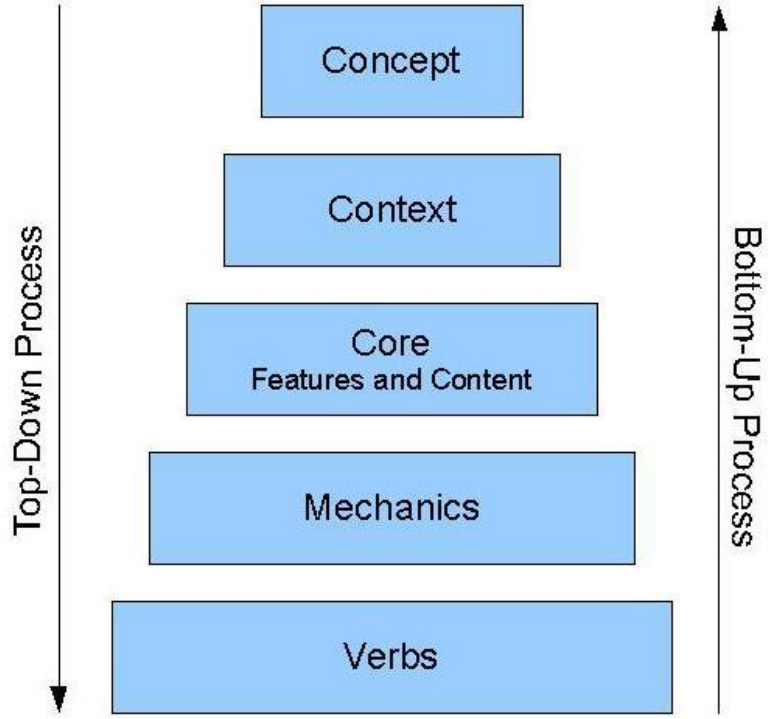


Figure 2-8 The layered view of the game design cognitive process (Lopes and Kuhnen, 2007)

Five layers of the game design cognitive process consist of:

1. **Concept layer** - It is an abstract description of an idea. It is created from phrases that describe style, setting, and other general matters in the game.
2. **Context layer** – It comprises any circumstances and motivations presented to the players. It defines a concrete view of the game that the players can refer to.
3. **Core layer –** It contains two components in this layer, content and feature. Content is the component of the game that player can see. Feature is the component of the game that describes what this game can do.
4. **Mechanics layer –** Game mechanics consist of rules which translate the inputs of the player to the intended output back to the player.
5. **Verbs layer –** It is the lowest layer of this model. It consists of a single action that the player can perform during the game. The action might be restrained with the game state which cannot be done depending on game rules.

The concept layer, context layer, and core layer are the top layers which identify a game. These three layers are varied from one game to another. While two other layers are the basic parts of each game. In each game in the same genre, some components in these two layers may be widely reused. For example, “Fire

a bullet" on Verbs layer which is translated to "To injure or kill enemies" on Mechanics layer are common in first-person shooting games, and "Stomp on an enemy" on Verbs layer which could be translated to "Get rid of enemies" are common in platform games. These layers of game design are useful when reviewing and discussing on augmented reality games later.

Regarding genres of games, games can be categorised into different genres using their gameplay style. Many game genres are classic genres which could be found in many games such as simulation, strategy, action, role-playing, etc. (Apperley, 2006). Nevertheless, since the potential of games is endless, many new genres have emerged through years. Therefore, it is suggested that game genres should be divided by the other factors rather than their gameplay such as setting, audience, theme, and purpose (Adams, 2009) or their aesthetics (Extra Credits, 2012a). However, whatever genres the games are categorised into, one genre that has recently been in the spotlight is pervasive games. This type of games is the superset of augmented reality games which will be reviewed in the next section.

2.1.3 Pervasive games and augmented reality games

As stated in the previous section, one type of video games that has recently been in the spotlight and has gained more interest is pervasive games. This kind of games extends the gaming experience into the real world using the features of computer hardware such as a camera, GPS, map, etc. and blends the in-game world with the physical world (Benford, Magerkurth and Ljungstrand, 2005). Pervasive games are believed to expand the gaming experience in three different directions - spatial, temporal, and social (Montola, 2005). Many recent paradigms of pervasive games have received a good attention and feedback. For instances, Ingress (Ingress, 2012), Pokémon GO (Pokémon GO, 2016), as well as a rising number of virtual reality games using virtual reality headsets such as Oculus Rift (Kickstarter, 2012), Playstation VR (Playstation, 2016), HTC Vive (Vive.com, 2017), and Microsoft Hololens (Microsoft HoloLens, 2017). This suggests that pervasive games have good potential in gaming industry.

Augmented reality game is one of the subsection types of mixed reality games and pervasive games, where "the real objects and virtual objects can co-exist and interact in the gaming environment" (Natkin and Yan, 2006). It adopts augmented reality technology into gaming which displays advantages from both sides to the users. By overlaying virtual game content on the real world, it expands gaming experience of the players. As mentioned in Figure 2-1, augmented reality game is the intersection of augmented reality and games. Therefore, it inherits some characteristics from both areas.

To begin exploring the augmented reality games topic, it is reasonable to firstly explore the history of augmented reality games to acknowledge attempts, approaches, and the current state of augmented reality games.

One of the first augmented reality games was AR-Quake which is an alternative version of the popular first-person shooting game 'Quake' (Thomas et al., 2000). By using a GPS and digital compass plus some tracking on fiduciary markers, the player can experience a shooting game in the real world. The player is equipped with a portable-size computer in a backpack and a head-mounted device with two input buttons which carry the action of firing the guns while the movements are performed by the player's movements.

In 2001, Reitmayr and Schmalstieg (2001) introduced a multi-user augmented reality system. The system performs by using LAN and wireless LAN to bring several users into a shared space. They performed a game of augmented reality chess as the example of their system which collaborates between a stationary user and a mobile user. This game of chess could be considered as one of the first multiplayer augmented reality games.



Figure 2-9 Demonstration of AR Chess (Reitmayr and Schmalstieg, 2001)

Human Pacman was introduced in 2003 (Cheok et al., 2004). In this game, an augmented reality game was presented in a form of a mobile device in a wide-area. The system was based on physical, social, and ubiquitous characteristics. By augmenting virtual Pacman Cookies in the real world and some real objects as the special cookies, the players can experience the game playing where the virtual world was blended into the real world harmoniously.



Figure 2-10 Augmented reality world through head-mounted display in Human Pacman (Cheok et al., 2004)

In the same year, the first commercial augmented reality game called 'Mozzies' was released as a bundled game in Siemens mobile phone (Mozzies, 2004). This game allowed the player to shoot virtual mosquitoes augmented upon a live video feed with the crosshair mark at the centre of the mobile phone screen. Mozzies was awarded the best mobile game in 2003 and it has been ported to many other platforms of mobile phones even until nowadays.

The Invisible Train was introduced in 2004 (Wagner et al., 2005) as an example of a board game using a multi-user augmented reality system on handheld devices. It runs on PDAs with a built-in camera. With markers and real wooden miniature railroad tracks, the players can steer a virtual train over them with their PDAs. The Invisible train is the first multiplayer game running on handheld devices.

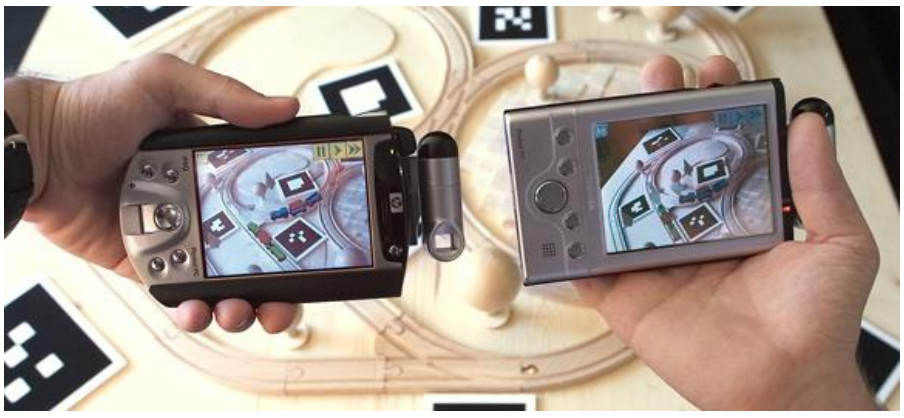


Figure 2-11 Invisible Train game play (Wagner et al., 2005)

Shortly after that, Henrysson, Billinghurst and Ollila (2005) presented AR-Tennis which was developed on Symbian phones using ARToolkit to

demonstrate possibilities of collaborative playing in augmented reality games. They connected two phones via BlueTooth. This game was awarded the 2nd International Mobile Game Awards' Grand Prix Winner and Best Technical Achievement in 2006 (International Mobile Gaming Awards, 2006). AR-Tennis is also the first collaborative augmented reality application on mobile phone.

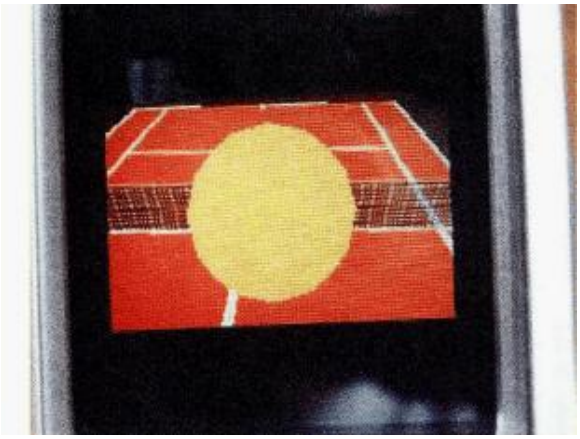


Figure 2-12 Player is hitting the ball in AR-Tennis (Henrysson, Billinghurst and Ollila, 2005)

A game with outdoor location-based augmented reality was introduced by Morrison et al. (2009) in their project 'MapLens'. In MapLens, two groups of participants, one using MapLens which is an augmented reality overlaying digital information on paper maps and the other using a standard 2D mobile map, were compared. It was found that 'AR features facilitate place-making by creating a constant need for referencing to the physical feature, and it allows for ease of bodily configurations for the group, encourages establishment of common ground, and thereby invites discussion, negotiation and public problem-solving. The main potential of AR maps lies in their use as a collaborative tool.'

After entering the smartphone era, there has been a steady increase of interest in augmented reality games along with the evolutions of the hardware. For example, in Georgia Institute of Technology's Computer Science courses, there is a module called 'Handheld AR Game Design' (Barba et al., 2009) of which the goal is to give students intensive experience in rapidly designing, prototyping and testing handheld augmented reality games. A project from this class was 'Joe Warpin' (AEL @ GT, 2009b), which later inspired an in-focus augmented reality game that is produced in a high quality at the level of commercial games called 'ARhrrrr!' (AEL @ GT, 2009a). These show the potential of augmented reality games where new possibilities of new augmented reality game playing styles are endless.

Augmented reality games are also key features of commercial console games. Sony PSVita, Nintendo 3DS, and Nintendo WiiU include the built-in augmented reality functions bundled with their hardware. Although the number of games is still relatively low comparing to the total amount of video games in the market, they still allow many new possibilities of gameplay to be introduced to the users.

Considering augmented reality games that have been released, it is suggested that augmented reality games can be played in a multiplayer setting without any problems. In fact, there have been many approaches on multiplayer augmented reality games which are expected to create a new sensation of playing games to the users. From the definition of games, players are one of the crucial factors. This characteristic is also inherited to augmented reality games. Therefore, in the next section, multiplayer in augmented reality games will be comprehensively explored to identify any possibilities or openings in this type of augmented reality games.

2.2 An observation on multiplayer augmented reality games and their analysis

Multi-user is a common feature in games nowadays. Multiplayer games where several players play in the same game are widely available in the market. This also applies to augmented reality games. In this section, multiplayer games and multiplayer augmented reality games will be highlighted. The characteristics and importance of essential components of multiplayer games will be reviewed. After that, multiplayer augmented reality games will be observed and analysed. This is expected to give an understanding of augmented reality games in a multiplayer aspect to explore improvements or diversities of multiplayer augmented reality games.

2.2.1 Multiplayer games and multiplayer augmented reality games

Multiplayer games use a benefit of a multi-user application feature into games. A multi-user system is translated literally as a system that allows multiple users to access the game at the same time (multi-user, n.d.). Multiplayer feature can be normally found in a game either in digital games such as classic Pong or non-digital games such as football and chess. Although it cannot be concluded that single player games are more appealing or more valuable than multiplayer games and vice versa, since it depends on the game setting and rules. However, it can be said that multiplayer is indispensable in the game field.

Multiplayer games involve various levels of components which have an influence on the overall gameplay. Peng and Hsieh (2012) stated that a

relationship among players has a significant impact in multiplayer games. The relationship among the players are divided into two types which are a pre-existing relationship or, in other words, a relationship in the real world, and an established relationship in games, in other words, social scenarios in games. These two types of relationships affect the motivation of the players in separate ways. However, since the pre-existing relationship is hardly defined in game design, it is, therefore, placed in a higher level than the established relationship in games which would affect all other components in games.

As defined in Section 2.1.2, games are composed of the players engaging in an activity which is defined by rules to give an outcome as win or lose conditions. Therefore, in multiplayer games, several players can engage in the same activity at the same time and create game's social scenario. However, the engagement of activity in a multiplayer game can be in many forms such as single player vs single player (e.g. boxing), group vs group (e.g. football), one vs group (e.g. tag game), all individual (e.g. athletics), individual side by side vs system (e.g. blackjack), and group vs system (e.g. many board games) (Tekinbaş and Zimmerman, 2003). Ultimately, these forms of multiplayer games are loosely divided into two groups – Competitive and Cooperative.

Competition and cooperation are the two bases of multiplayer activities (Deutsch, 1949), which are also applied to multiplayer games. Some may point out the third category as collaborative games (Zagal, 2006) but it can be said that collaborative games are also in the range of cooperative games. Generally, competitive and cooperative games are different in terms of a social relationship between the players and goals of each player. Interestingly, it is worthwhile to mention that competitive multiplayer games and cooperative multiplayer games improve the effort and motivation of the players from the single player version, especially in exertion games (Peng and Hsieh, 2012) where their mechanics are close to pervasive games. This, however, depends on many components, depth, and complexity of the game structure.

From Peng and Hsieh (2012), the social scenario is a crucial component. However, this is one of the top definable levels in multiplayer games. When a game designer defines a relationship between the players as cooperative or competitive, it does not only affect the player's roles and goals which inspire each player's behaviours and decisions (Tekinbaş and Zimmerman, 2003), but also the game rules themselves.

Apart from relationships among the players in the game, there is another concern of multiplayer games which is derived from the time-space taxonomy of computer-supported cooperative work (Johansen, 1988). Although multiplayer games involve many players playing a game together, they can play the game at the same or different time and places. This classification can be written in a matrix as shown in Table 2-1.

	Same space	Different space
Same time	Same time, same space	Same time, different space
Different time	Different time, same space	Different time, different space

Table 2-1 Computer-supported cooperative work time-space taxonomy matrix

There are many examples of multiplayer games on each type of space and time which are different in game rules, settings, and components. For example, twenty-two players play together in the same space and time in a football game, while several players play in the same space but at different times in a weightlifting game. Some online video games offer a period which allows players to participate in a huge single guild war. This occurs at the same time but in different spaces. While some online video games let the players 'send' a troop of soldiers to attack the other player's castle and wait over time to see the result if the attack is successful. This occurs in different times and spaces. It means that deciding whether a game happens in the same or different times and spaces will put an impact on the overall gameplay.

Another component that has an impact on and is crucial to multiplayer games is an interaction among the players (Dourish, 1998). This component is delineated by the game rules and the defined social scenarios. The interaction between the players could be an in-game interaction which is allowed by game rules, physical interactions which may or may not be authorised by the game rules, and verbal interactions which normally does not have an effect in the game rules but indirectly affect the other player's behaviours and decisions, in which an impact from these interactions will be put back to the overall group gaming experience (Bluemink et al., 2010).

These influential components in multiplayer games are layered and visualised as shown in Figure 2-13.

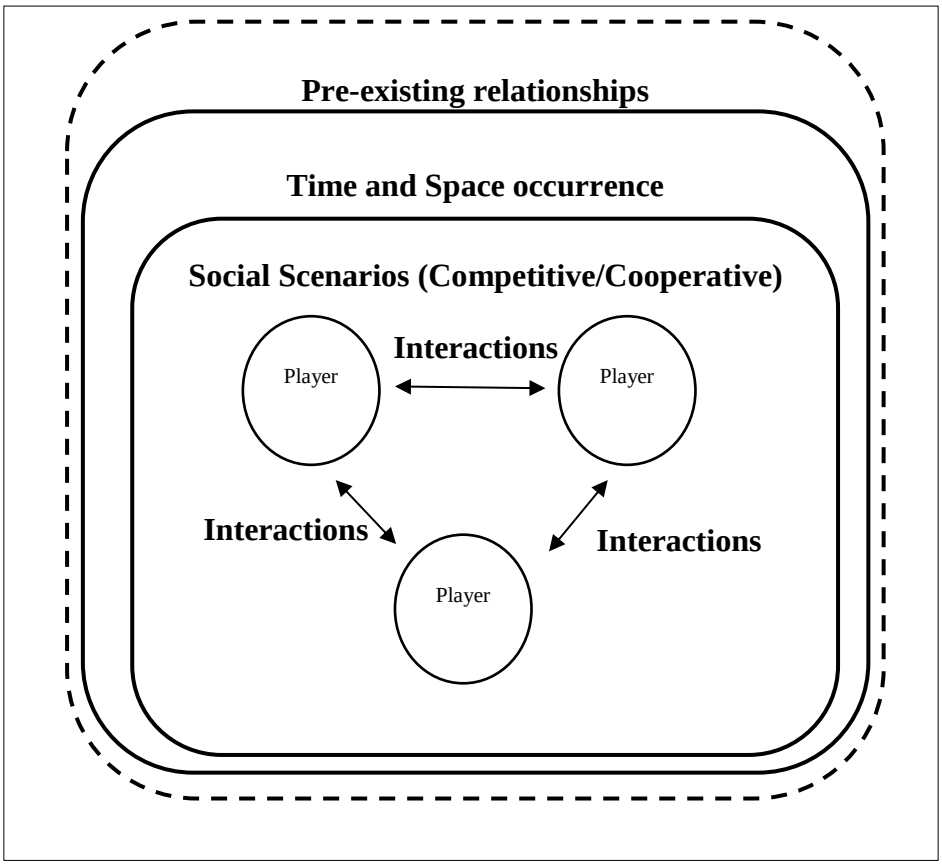


Figure 2-13 Multiplayer games influential components in different layers

Back to ***multiplayer augmented reality games***, there are augmented reality games which include multi-user features. The multi-user features overlap the relationship of augmented reality technology and games in Figure 2-1. The relationship of multiplayer augmented reality games is now modified as in Figure 2-14.

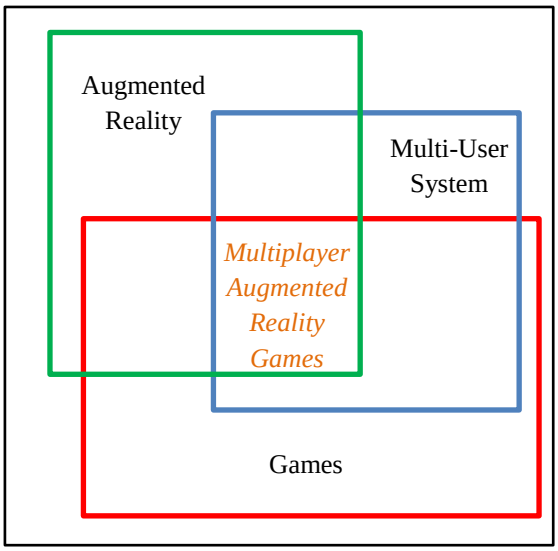


Figure 2-14 Multiplayer augmented reality games Venn diagram

Multiplayer augmented reality games inherit the characteristics from augmented reality games, e.g. real world and virtual world attributes, and multiplayer games, e.g. multiplayer game influential components, as presented before in the sections above. However, Montola (2005) explained that a pervasive game, which includes augmented reality games, further expand a regular game in three ways: spatial, temporal, and social. Augmented reality games blur the boundaries of a regular game which are space and time of playing and, more importantly, social scenario and how the players interact with each other. Therefore, as in Figure 2-13, augmented reality games expand multiplayer games in every layer of components which is influential to gameplay and game experience.

In the next section, the multiplayer augmented reality game topic will be analysed with three main concerns of multiplayer augmented reality games that presented before: Montola's three key expansion of pervasive games, Johansen's time-space taxonomy of computer-supported cooperative work, and Milgram's reality-virtuality continuum. This is to identify any openings in the multiplayer augmented reality game topic that could be further explored as the focus of this thesis in further chapters.

2.2.2 Analysis of multiplayer augmented reality games

The multiplayer augmented reality game topic is the intersection area of augmented reality games and multiplayer games. Each area has its own characteristics and properties where most of them are inherited to multiplayer augmented reality games. Moreover, these characteristics and properties are additionally expanded by their combinations. These create enormous potential to the multiplayer augmented reality game topic. However, as the topic is rather new, there might be some openings which could be further improved. Therefore, the topic is going be analysed in this section using three concerns of augmented reality games, multiplayer games, and pervasive games. A number of academic and commercial multiplayer augmented reality games, which are considered a turning point to the technology at their times, will be observed. At the end of this section, it is expected that gaps in the multiplayer augmented reality game topic will be identified before their fillings are introduced in the further sections.

Analysed multiplayer augmented reality games

At each point of augmented reality games history, several games contain a multiplayer feature and have a significant impact on game experience. These games have similar and different features and properties. Some games were presented before in the earlier part of this chapter. Since they have influenced

the topic in their era, they are good examples and starting points to observe and analyse for an introduction of the multiplayer augmented reality game topic. They are listed here as a reference for further point of the section.

AR Chess (Reitmayr and Schmalstieg, 2001) is one of the first augmented reality games which contain a multiplayer feature. It was created to demonstrate the potential of a mobile augmented reality kit which was an advanced technology at the time. However, the demonstration also presented a new possibility of a system which contains multiple players and viewers at the same time.

Human Pacman (Cheok et al., 2004) is an augmented reality game which is derived from the Pacman game. It demonstrates how multiple players play an augmented reality game in a wide area of the real-world space. Players are divided into two sides and compete. Additionally, the viewers can access the game environment via the network without any physical presence. These viewers take a 'helper' role to advise each player from the god-eye view. This created a hybrid environment of the actual and virtual players. The feature leads to a mixed reality feeling.

Invisible Train (Wagner et al., 2005) is the first multiplayer augmented reality game on handheld devices. It reduces the size of multiplayer augmented reality systems from the 'mobile' backpack and head-mounted display augmented reality kit to handheld lightweight PDA. Furthermore, it overlays and runs a virtual train on a real wooden miniature railroad track, which demonstrates how virtual and real objects correspond in the same space.

AR-Tennis (Henrysson, Billinghurst and Ollila, 2005) is the first collaborative augmented reality game on a mobile phone. It demonstrates the value of augmented reality in the system and differences in user experience between face-to-face and non-face-to-face conditions in collaborative augmented reality environment.

MapLens (Morrison et al., 2009) presents a location-based treasure hunt game in a large area. It compares a usage of an augmented reality map system to a 2D standard digital map. However, what MapLens demonstrates is how the players use communication in the real world to collaboratively process the game.

Ingress (Ingress, 2012) is one of the first global-size commercial multiplayer augmented reality games. It uses real-world landmarks to be the objective points in virtual environment. It demonstrates how the players traverse in game environment using the player's transition in the real world, also cooperative and competitive gameplay of the players in the whole world in the mixed reality space.

Pokémon GO (Pokémon GO, 2016) is a global-sized commercial augmented reality game which inherits some features from Ingress. It deploys the feeling of exploratory and collectional gameplay from a famous game series 'Pokémon' into the real-world exploration. Furthermore, it demonstrates an interesting relationship among the players. It does not form strong cooperative bonds within the same side of players as in Ingress and the players are more likely to play individually in the virtual world. However, the players from every side intensively collect and exchange information of the game in the real world whether online or in person nearby.

Analysis from augmented reality aspect

The first aspect that the listed augmented reality games are analysed from the augmented reality aspect. Recalling Figure 2-2, augmented reality is a subset of mixed reality between the real and virtual environment and can be presented in reality-virtuality continuum (Milgram et al., 1995). Augmented reality is normally placed towards the real environment side since the definition of augmented reality, as mentioned in Section 2.1.1, is "the supplement of the virtual objects and the reality by superimposing the objects upon or compositing with the real world" (Azuma, 1997). In other words, reality is expanded with virtuality. The regular position of augmented reality on the continuum is shown in Figure 2-15.

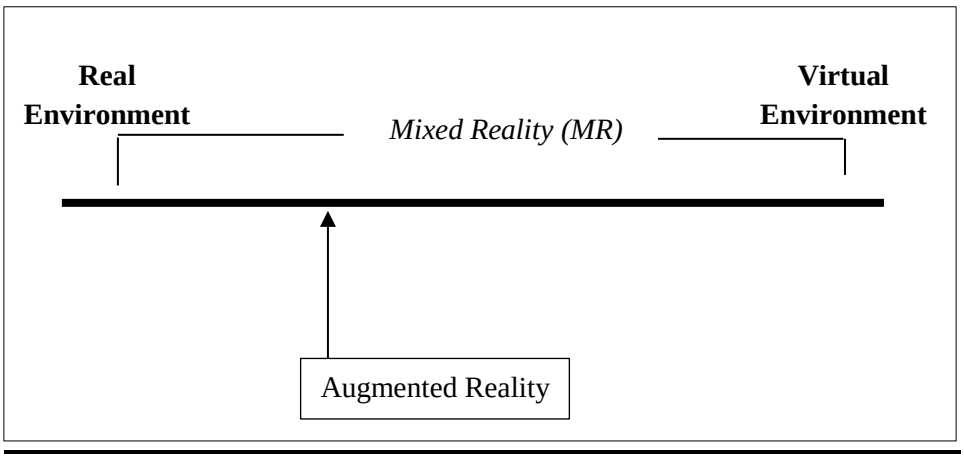


Figure 2-15 Augmented reality on reality-virtuality continuum

Nonetheless, components in augmented reality can still be placed at different points on the continuum. For example, markers in the augmented reality system are part of the real world but it also has an important role in the augmented reality world. Therefore, markers should be placed more towards to the real environment side than the overall augmented reality system. Likewise, each

component of augmented reality can be on overlapped environment to create this augmented reality environment and mixed reality experience to the users.

Using this classification to distinguish components in multiplayer augmented reality games that are listed above, components in multiplayer augmented reality games can roughly be divided into five major groups.

1. Real objects

Real objects in multiplayer augmented reality games are the objects in the real world which do not have any direct connections to or not visible in the augmented reality environment. This kind of components is placed at the end of the real environment side, which means they are fully in the real environment and do not involve with the events in the augmented reality environment, as shown in Figure 2-16.

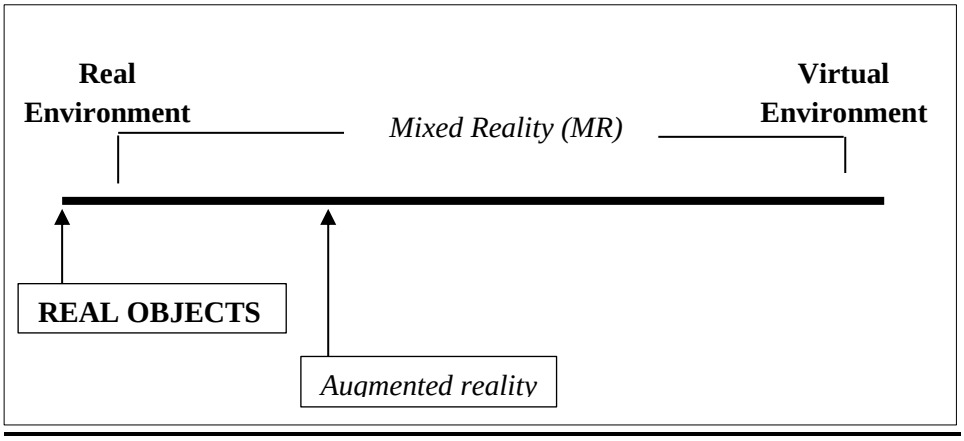


Figure 2-16 Real objects on reality-virtuality continuum

In listed multiplayer augmented reality games, a real object which appears in every game except Human Pacman, Ingress, and Pokémon Go is the *players* in those games. There are also additional real objects specifically to each game, for example, special cookies in Human Pacman which are real objects that the Pacman-side player needs to find in the game area, markers in Invisible Train which are the reference points of detection algorithms but do not directly play any roles in the game, markers in AR Chess and AR Tennis which are fully covered with virtual objects and are not visible in the mixed reality environment, etc.

2. Augmented objects

These are typical objects in the augmented reality system. They are part of mixed reality environment towards the real environment side. Mostly, they are virtual objects which are augmented to some real objects and change their positions, orientations, or even appearances per the amendment of those real objects. This kind of components is placed at the same point as regular augmented reality environment, as shown in Figure 2-17.

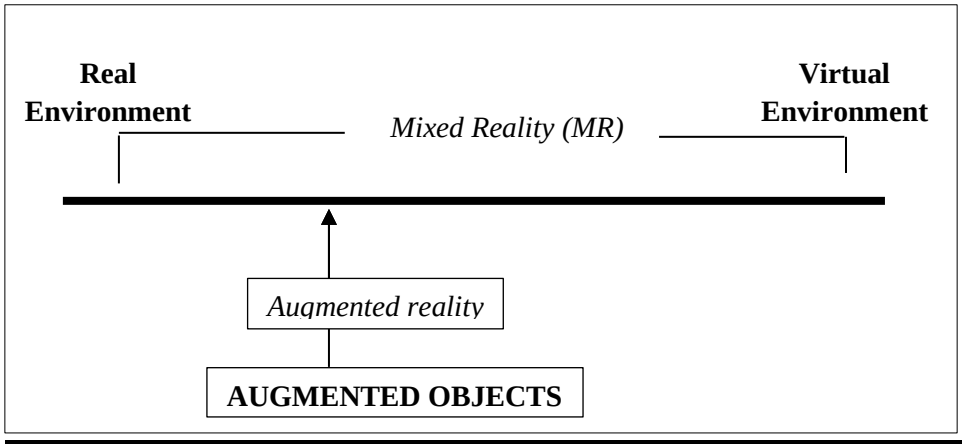


Figure 2-17 Augmented objects on reality-virtuality continuum

There are several things in listed multiplayer augmented reality games which are categorised in this type of components – as listed below: -

AR Chess: *Chess board, Virtual Pen.*

Human Pacman: *Virtual cookies.*

Invisible Train: *Virtual trains.*

AR Tennis: *Tennis court, Tennis net, Tennis rackets.*

MapLens: *Virtual navigation.*

Ingress: *Avatar, Portals.*

Pokémon Go: *Avatar, PokéStops, Gyms, Pokémon in catching screen with AR option on.*

3. Virtual objects

Contrasting to real objects, virtual objects are the objects in the virtual world which do not have any direct connections to the augmented reality

environment and are not augmented to the augmented reality scene. It is placed at the end of the virtual environment side, which means they are fully in the virtual environment and do not involve with the events in the augmented reality environment, as shown in Figure 2-18.

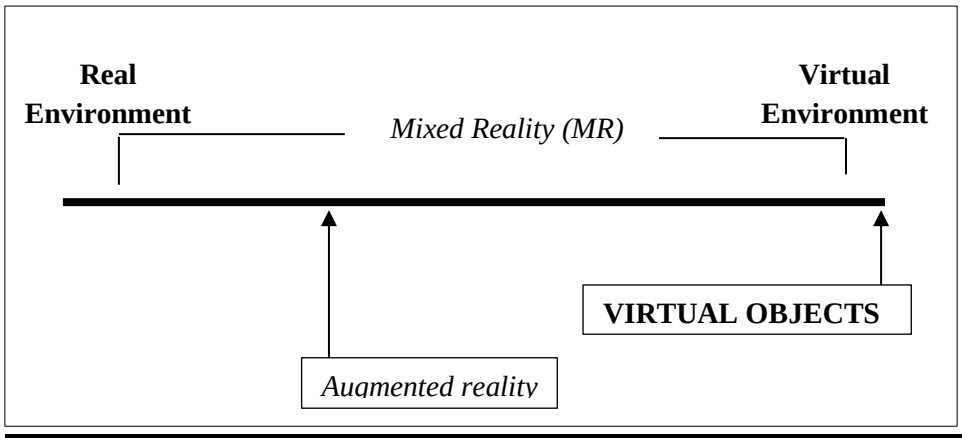


Figure 2-18 Virtual objects on reality-virtuality continuum

In listed multiplayer augmented reality games, there are a few things that are considered virtual objects. For example, helpers who advise players by a text-based chat but cannot be physically involved in Human Pacman, in-play items in Ingress and Pokémon Go, and Pokémon in catching screen with AR option off in Pokémon Go.

4. Partial augmented real objects

This kind of components is real objects in real environment. However, they are also part of the augmented reality environment and mixed reality world. They are normally visible in an augmented reality scene and involve some virtual objects in the scene. On reality-virtuality continuum, it is placed more towards to the real-environment end than augmented objects, as shown in Figure 2-19.

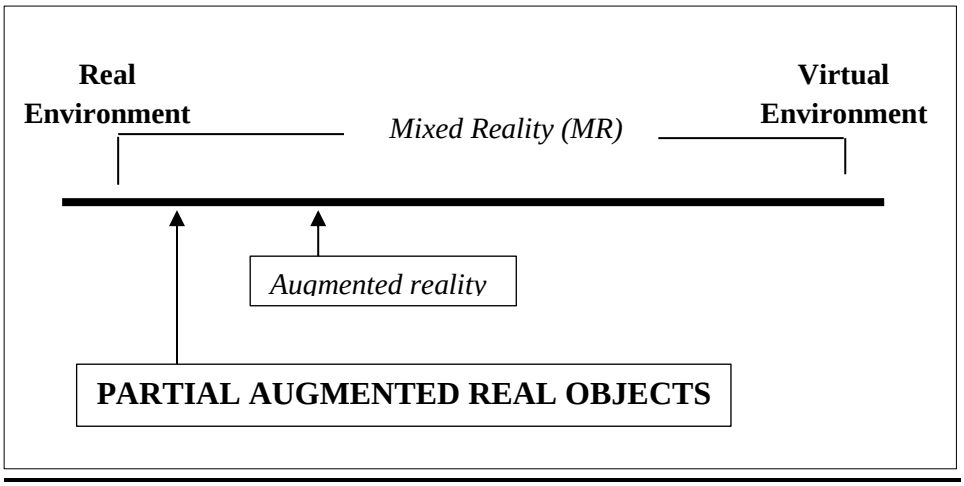


Figure 2-19 Partial augmented real objects on reality-virtuality continuum

In listed multiplayer augmented reality games, the examples of the partial augmented real objects are a wooden miniature railroad track in Invisible Train as it is visible in the scene and the track that virtual train rides on, a real map in MapLens as it is the reference point for virtual objects and not fully covered, and the player in Human Pacman, Ingress, and Pokémon Go as an avatar in the game is moved per player's movement in the real world.

5. Partial augmented virtual objects

This last kind of components is virtual objects which are augmented to the augmented reality scene. Yet, they are not fully attached to the real world. The objects that move on a virtual plane, for example, is augmented on augmented reality marker. On reality-virtuality continuum, it is placed more towards the virtual-environment end than augmented objects but not beyond the half point of the continuum which is considered the point where reality is transited to virtuality, as shown in Figure 2-20.

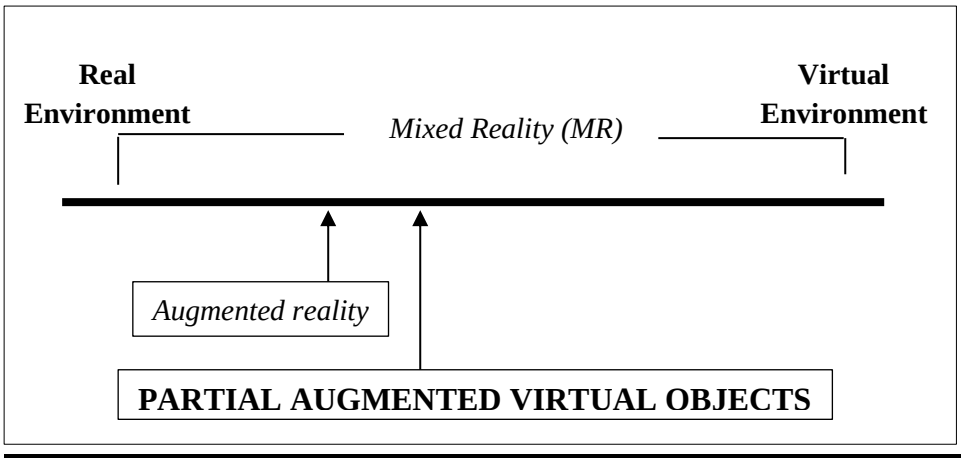


Figure 2-20 Partial augmented virtual objects on reality-virtuality continuum

In listed multiplayer augmented reality games, the examples of the partial augmented virtual objects are chess pieces in AR Chess, a tennis ball in AR Tennis, portal links and a captured area in Ingress, and Pokémon on map screen in Pokémon Go.

These five groups are components of multiplayer augmented reality games. This shows that although overall multiplayer augmented reality game experience has its position on the reality-virtuality continuum, its components spread their positions across the continuum to create the mixed reality experience on their own. Most importantly, all components, wherever their position is, have their roles and equal importance compared to the other components.

However, multiplayer augmented reality games sometimes neglect or give precedence to some kinds of components. Any parts in multiplayer augmented reality games which are not involved in the augmented reality are sometimes ruled out from the game. The importance of player's existence, for example, do not have an important role in some games as the games focus on the augmented reality environment.

Analysis from multiplayer game aspect

The second aspect that the listed augmented reality games are analysed is from the multiplayer game aspect. As mentioned in Section 2.2.1, one of the concerns in multiplayer games is time-space taxonomy which is derived from the time-space taxonomy of computer-supported cooperative work (Johansen, 1988). Recalling Table 2-1, playing a multiplayer game can happen at the same or different times and spaces. Because of this, on closer inspection of listed

multiplayer augmented reality games, they can be divided roughly into two groups per their size of playing space, corresponding to this time-space taxonomy.

Large-field gameplay

This group of multiplayer augmented reality games present their gameplay in an enormous size of area. Their playing area is most likely to be far beyond the reaching distance of the player's arms. This creates the gameplay that relies on actions that each player performs individually, and the status is communicated through the wireless connection. The listed multiplayer augmented reality games in this group are Human Pacman, MapLens, Ingress, and Pokémon GO.

In time-space taxonomy matrix, this group lies in 'Different space' cells. The highlight of this group is asynchronous gameplay where individual player's actions take the higher priority than interactions between the players. Players will consider the game situations and appointed social scenario, then decide on their individual actions which will affect the game situation. Interactions between the players could be done mostly either in-game or verbally. The physically interactions tend to occur low in number due to the enormous size of the playing area. Ultimately, the augmented reality feature will be used to carry the message to players and enhance the realistic feeling. The augmented reality concentrates on the player's side rather than the other players' side.

	Same space	**Different space**
Same time		Sometimes
Different time		Normally

Table 2-2 Large field augmented reality games in time-space taxonomy matrix

Near-field gameplay

The other group of multiplayer augmented reality games is the group that presents a gameplay within a limited reachable size of area. This group resembles many traditional multiplayer games such as football, chess, tag, tug of war, rock-paper-scissor, and several more. The example academic augmented reality games which are categorised in this group are AR Chess, Invisible Train, and AR-Tennis.

In time-space taxonomy matrix, this group lies in 'Same space' cells. The highlight of the near-field gameplay group, considering on traditional multiplayer games, is that interactions between the players are as important as individual decisions, depending on the game design. The interactions could be either in-game, verbal, or physical. These interactions put great impacts on individual decisions, actions, and game situation (Bluemink et al., 2010).

	Same space	Different space
Same time	Normally	
Different time	Sometimes	

Table 2-3 Near-field augmented reality games in time-space taxonomy matrix

From the augmented reality point of view, ideally the near-field gameplay should add the virtual superimposition on all detectable objects and players, in addition to individual virtual augmentation. This could increase the opportunities of gameplay creations which could enhance the game experience for each player, which is the one of purposes of augmented reality. However, it can be difficult to superimpose every single object in the scene. However, the more this can be done, the more enhanced the experience in augmented reality will be.

Analysis from pervasive game aspect

The last aspect to be analysed is from a pervasive game aspect. Montola (2005) proposed that pervasive games expand the boundaries of regular games which "are played in certain spaces at certain times by certain players" (Montola, 2005) in three different directions: spatial, temporal, and social. In this section, the listed multiplayer augmented reality games are analysed to identify how they expand the gaming experience in these three directions and what the impacts they are from these expansions.

Spatial expansion

Pervasive games expand their playing location into a wide area or globally. This expansion is coordinated with the time-space taxonomy in the previous

section, as the size of the playing area increases along with the expansion and the players might not play in the same place.

This expansion is obvious for the game with a large-field area. Human Pacman and MapLens expand the size and place of game playing from in front of the computer into a wide field. Likewise, Ingress and Pokémon Go increase the size of the game to the global scale. These create unique experience to the players when they play these games.

On the other hand, it is not necessary that near-field games do not contain this expansion. The expansion is not attached only to the size of the playing area, but also the place where the game occurs. AR Chess does not provide an obvious expansion since the regular chess game is also a table-top game. However, AR Tennis and Invisible Train provide this expansion. Games that are normally played in the large field are diminished and played on a table, an unfamiliar space to the gameplay.

Temporal expansion

Pervasive games expand the playing time of the gameplay and sometimes blur the starting and finishing points of the game. Montola (2005) stated that temporal expansion ties with social expansion as players might not be aware whether they are playing the game or not so in-game and a real-life social scenario might be different.

This expansion is not noticeable in some listed multiplayer augmented reality games as they show clear playing time like other regular games. For example, AR Chess, Human Pacman, Invisible Train, MapLens, and AR Tennis.

However, Ingress and Pokémon Go display this temporal expansion. Playing these games can be part of the players' life as they travel, shopping, exercise, etc.

Social expansion

The last expansion of pervasive games is social expansion. Pervasive games expand how a relationship between people, who are players, is and blur the boundaries of in-game and real-life relationships between the players. As stated in Section 2.2.1, the relationships among the players and assigned social scenarios have an impact on the interactions between them. These influence individual decisions, behaviours, and actions which, subsequently, affect the overall whole-group gaming experience.

AR Chess is an example of a one-on-one competitive social scenario. The players' relationship is simply laid out to compete against each other. On the other hand, AR Tennis and Invisible Train display a one-on-one cooperative social scenario where nobody wins. Human Pacman shows a one-versus-group competitive scenario while MapLens presents a group-versus-group scenario. Nonetheless, as mentioned in the previous section, these examples have clear playing time. Therefore, relationships in game are not expanded into the real life.

However, Ingress and Pokémon Go expand relationships between players and intervene into real life. Each player can be in the same or separate groups in the game which is overlaid on their real life social scenarios and distort their overall relationships.

Overall analysis on multiplayer augmented reality games

An analysis of three aspects of multiplayer augmented reality shows that some parts of the game have been neglected on each aspect. For example, on the augmented reality aspect, the players are a component in every game that has been analysed. In most of those games, the players are categorised in Real Objects category, which are not directly involved with the gameplay. It almost appears that the players are ignored from the gameplay. However, the player's existence is the main point of any games (Montola, 2005), especially multiplayer games. These create some more following openings in those games.

Based on the assumption that the player is one of neglected components, focusing on near-field multiplayer augmented reality games which are played in a limited reachable size of area, this kind of games resembles a lot of physical games where the existence of the players is emphasis. Since augmented reality games are pervasive games which are a hybrid between digital games and physical games. Therefore, near-field multiplayer augmented reality games should adopt advantages from both multiplayer digital games and multiplayer physical games. In multiplayer physical games, the players normally physically engage in in-game relationships with each other. This plays a key role in the game such as tug-of-war, football, or athletics. Even in several near-field pervasive games such as Johann Sebastian Joust, a good attention is paid to the player's existence. As well as in several multiplayer digital games, the players are always important in gameplay mechanics. However, this attribute is hardly adopted to augmented reality games.

In seven analysed multiplayer augmented reality games, Human Pacman, Ingress, and Pokémon Go recognise the existence of the players and include them in the game mechanics. However, none of them is near-field augmented reality games. It appears that players in near-field multiplayer augmented reality

games disappear from the game scene. Most of the regular near-field multiplayer augmented reality games concentrate only on the common space between the players which the game emerges (Reitmayr and Schmalstieg, 2001) or does totally not recognise the existence of the other players at all (Wagner et al., 2005). Players normally interact with in-game objects e.g. markers, virtual objects, on-screen interface, etc. and hardly interact with each other, as shown in Figure 2-21.

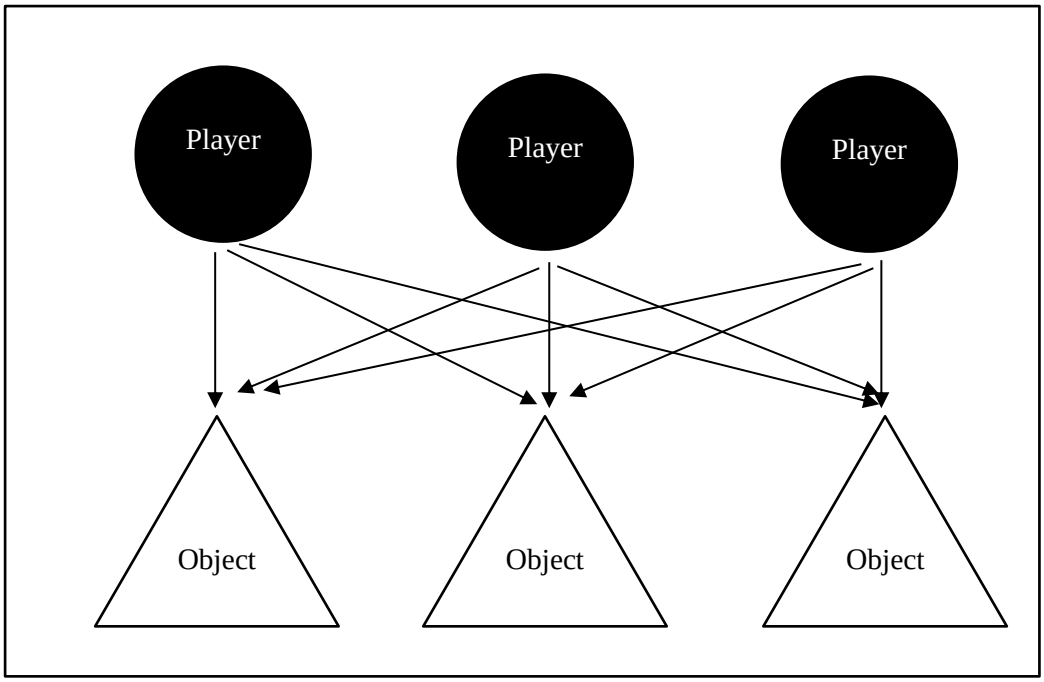


Figure 2-21 Diagram of interactions between players and objects in regular near-field multiplayer augmented reality games

This neglects the importance of the players who are also a member of the mixed reality environment in augmented reality games. This also abandons social interactions among the players, which is one of the key points of multiplayer games (Peng and Hsieh, 2012) and contradicts with pervasive game's social expansion gaming experience (Montola, 2005). Therefore, this is the opening that this thesis is going to challenge and explore in the rest of the thesis.

2.3 Establishing the core research topic: Introduction of face-to-face augmented reality games

As discussed in the previous section, the feature which is absent from these games is interactions among the players. These interactions could be any types of engagement whether they are physical or verbal. However, verbal interactions do not normally have an effect in the game rules directly but instead

indirectly affect other player's behaviours and decisions. Therefore, a type of interactions that should be of interest is physical interactions among the players. These physical interactions will be the main concern of the absences in the current multiplayer augmented reality games and ideally purposed in Figure 2-22.

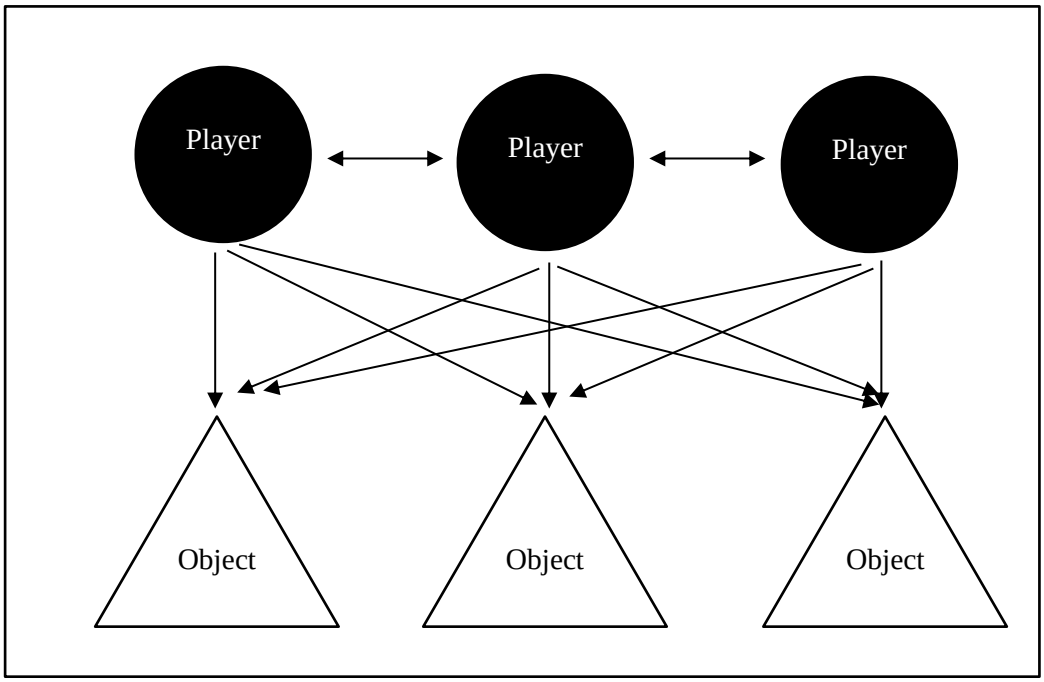


Figure 2-22 Diagram of interactions between players - players and players - objects in the proposed setting of multiplayer augmented reality games

Physical interactions between the players are from their physical movements. Ideally, if all players' existence and movements are detected by the system and play the important part in gameplay mechanics, the current absences of multiplayer augmented reality games should be fulfilled. Moreover, any necessary virtual images can be overlaid in correspondence with those detections to enhance the gaming experience and shorten the gap between the real world and virtual world. However, the limitations of camera range of view could put a big constraint on the detection and augmentation of the other player's action with virtual objects. Even though it is possible to rely on additional sensors apart from the vision from the camera for more information about the current state of other players, it is still difficult to detect the entire movements and state in real time.

Nonetheless, in a near-field gameplay, there are several situations where the players are playing in a face-to-face situation even if the gameplay is not entirely face-to-face. For example, in football, there are eleven players playing on each side and the game occurs in the football field which is larger than the reaching range of arms. However, each player eventually confronts each other in a face-

to-face situation such as a one-on-one duel between two players. These usually happen in the other regular games, either digital or non-digital.

In the AR-Tennis study (Henrysson, Billinghurst and Ollila, 2005), the players were put in a face-to-face situation and the importance of superimposed objects during the gameplay was studied. The study shows that augmented reality enhances face-to-face gaming experience. However, the backward study which is how a face-to-face situation enhances augmented reality experience, including the physical interactions between players which is the neglected point, has not been studied. Truthfully, most of augmented reality games do not include any physical movements into the game process. In NerdHerder game (Mendenhall et al., 2012) the physical movements were ambitiously included into augmented reality games which, in return, received well-feedback from the users. This suggests that physical movements are an important part in a face-to-face situation. These physical movements satisfy the point of absence of interactions among players and translate into part of game mechanics. Therefore, these **face-to-face multiplayer augmented reality games** are a noteworthy interesting topic to explore more in this thesis.

Multiplayer augmented reality games conspire with three major areas which are augmented reality technology, games, and a multi-user system as shown in Figure 2-14. Face-to-face situation of two users is a subsection of the multi-user system. Therefore, face-to-face augmented reality games could be visualised as in Figure 2-23.

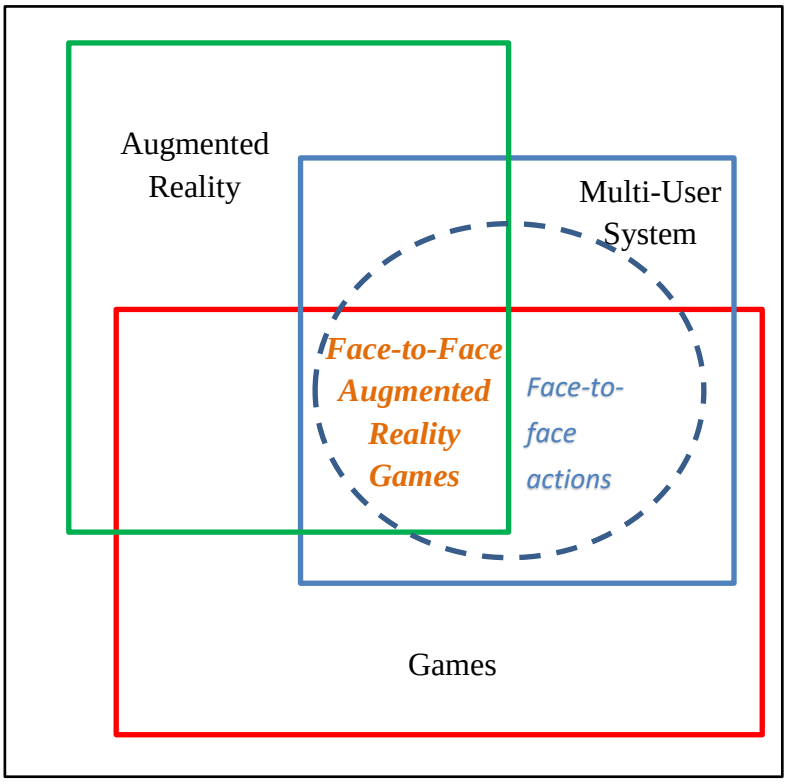


Figure 2-23 Face-to-face augmented reality games Venn diagram

2.4 Conclusion

In this literature review chapter, the multiplayer augmented reality game topic has been introduced as the intersection area of augmented reality technology, games, and a multi-user system. Each area was explored in detail including their history, characteristics, components, and concerns. Augmented reality technology has been introduced as a subset of mixed reality environment where the real world and virtual world co-exist. Milgram's real-virtuality continuum (Milgram et al., 1995) was presented to show the spectrum of mixed reality environment between the real environment and virtual environment which is the basis of mixed reality exploration. Process, architecture, types of display, and application categories of augmented reality technology were reviewed. After that, the games topic was visited in terms of its definition, layers of games, and genres of games. These together introduced pervasive and augmented reality games.

Pervasive games were reviewed as the games that blend the in-game world with the physical world (Benford, Magerkurth and Ljungstrand, 2005) and expand gaming experience in spatial, temporal, and social orientations (Montola, 2005). Augmented reality game topic is a subset of pervasive games. Several previous augmented reality games were presented to provide the history, developments, and potentials of the technology. When combining with a multiplayer feature to create a multiplayer augmented reality game area, their potentials and characteristics are still present.

To identify an opening in multiplayer augmented reality games, the topic has been analysed using core concerns of its three component areas: Milgram's reality-virtuality continuum (Milgram et al., 1995), Johansen's time-space taxonomy of computer-supported cooperative work (Johansen, 1988), and Montola's three key expansion of pervasive games (Montola, 2005) by using a number of academic and commercial multiplayer augmented reality game examples. As the result, it showed that players and interactions among them are neglected in the topic and studies although they are an important part of multiplayer games. To be more specific, **face-to-face interactions in multiplayer augmented reality games** is the main research topic in the rest of this thesis.

Chapter 3

Concept of face-to-face augmented reality games

The literature on the multiplayer augmented reality topic that has been reviewed in Chapter 2 suggested that face-to-face interactions among players is one of the social interactions that has been neglected. This provides the core interest of the forthcoming research in this thesis. At the outset, the topic of face-to-face interactions in multiplayer augmented reality games need to be reviewed thoroughly before the areas of topic study are established. This chapter investigates face-to-face interactions in augmented reality games in three major parts: its foundations, feasibilities of the topic, and its possibilities in terms of its applications. These provide the essential background concept along with the understanding of the limitations and potentials of the topic. By the end of this chapter, all these three major parts will substantially establish the areas of topic study for the next chapters.

3.1 Face-to-face augmented reality games foundations

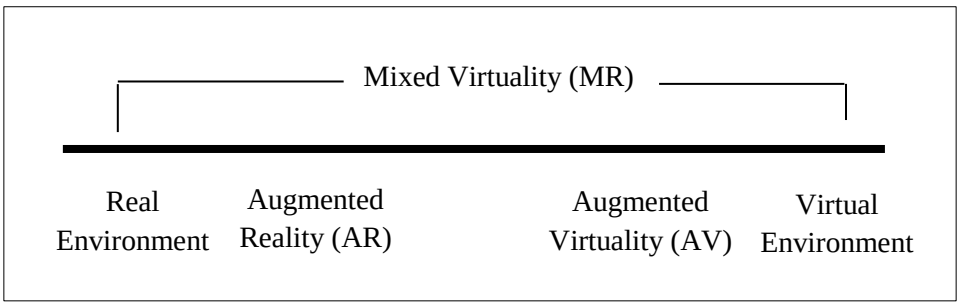


Figure 3-1 Paul Milgram's Reality-Virtuality Continuum (Milgram et al., 1995)

The reality-virtuality continuum (Milgram et al., 1995) in Chapter 2 shows that augmented reality occurs in between the virtual world and the real world. In other words, it occurs at the same time in both worlds. Therefore, any events in an augmented reality application can be settled in either world or the world in between and they all affect each other. The diagram below is an expansion of reality-virtuality continuum that visualises events in an augmented reality application.

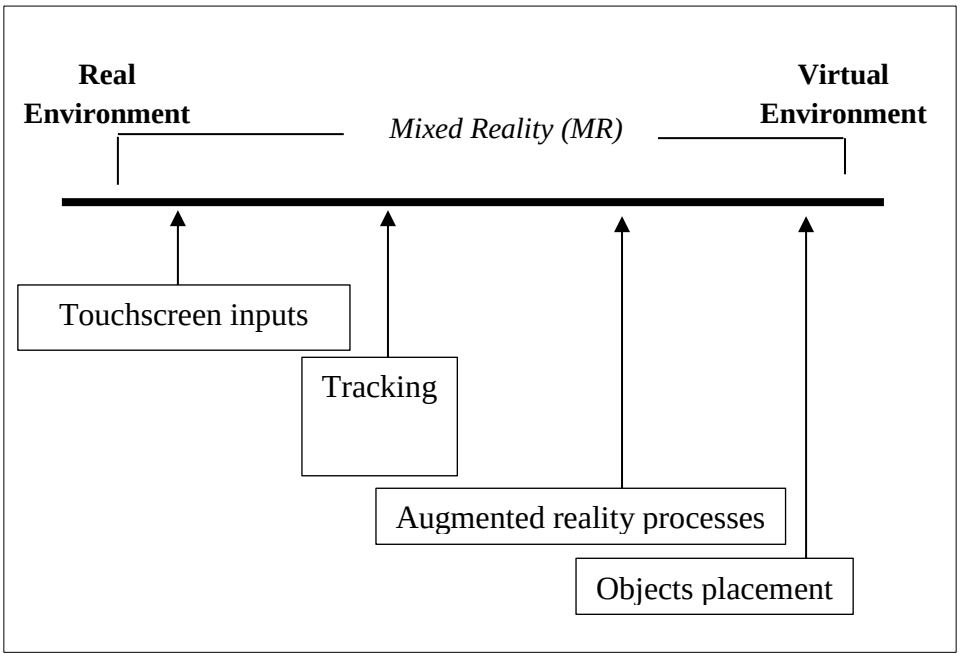


Figure 3-2 An expansion of Reality-Virtuality Continuum for augmented reality events

The diagram shows various parts and events of an augmented reality application that occur in the real world, the virtual world, or the world in between. All of these events are essential and cannot be ignored. On the input part, a typical augmented reality application uses an input mainly from a touchscreen, corresponding occasionally with some sensors such as an accelerometer and a gyroscope. However, in NerdHerder game (Mendenhall et al., 2012), the physical movement inputs and feedback were ambitiously included into augmented reality games which, in return, received a good reception from the users. This suggests that physical movements can be an important part in a face-to-face situation. For this reason, face-to-face interactions are intended to be included in multiplayer augmented reality games to expand the inputs in the real world as well as amplifying the importance of other players in the game. This should influence every other part of augmented reality in every world and give many more possibilities to multiplayer augmented reality games.

Typically, physical movements of one body are operated in six degrees of freedom. An interaction between players in an augmented reality space requires

to know current positions and orientations of the other players. One of the straightforward methods, which is the method used for the studies in this thesis, is placing an augmented reality marker at the back of each handheld device. This allows the other players to track the position and orientations of that device relatively to the observing device using a computer vision and augmented reality algorithms. An example setting of face-to-face augmented reality is shown below.



Figure 3-3 An example of face-to-face interactions tracking between two players

As mentioned above, this setting can track only a relative movement between two devices. If any absolute movements of the device are required, other information from the sensors is needed to be taken into consideration, e.g. an accelerometer, a gyroscope, etc. This will be explained later as the thesis proceeds.

Any relative movements between any two devices are in six degrees of freedom. This means the device's position and orientations appear to be able to be moved freely in the observer's perspective, but they are moved along or rotate about axis in three dimensions.

Position translations involve moving a body from one position to another in a three-dimensional space without changing its orientations. However, relative movements that cause position translations can either be the observed object's transition or observer's transition, as shown in Figure 3-4.

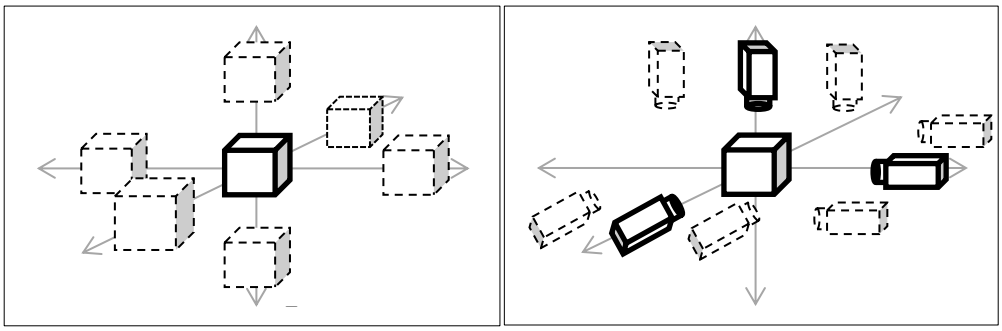


Figure 3-4 Position translations in three-dimensional axis
(Left) object's transition (Right) observer's transition

On the other hand, orientation rotations involve rotating a body around a line in a three-dimensional space. There are several types of orientation rotations but the one used in this thesis is aircraft principal axes which consist of three types of rotation: roll, yaw, and pitch. Roll rotation is to rotate clockwise or counter-clockwise around the axis that is drawn from the front of the body through the tail. Yaw rotation is to rotate left or right around the axis that is drawn from the top of the body through the bottom. Pitch rotation is to rotate up or down around the axis that is drawn from the left side of the body through the right side. These aircraft principal axes are proposed to ground a mutual understanding with the rotations. Like position translations, relative movements that cause orientation rotations can either be the observed object's rotation or observer's rotation. These orientation rotations are shown in Figure 3-5.

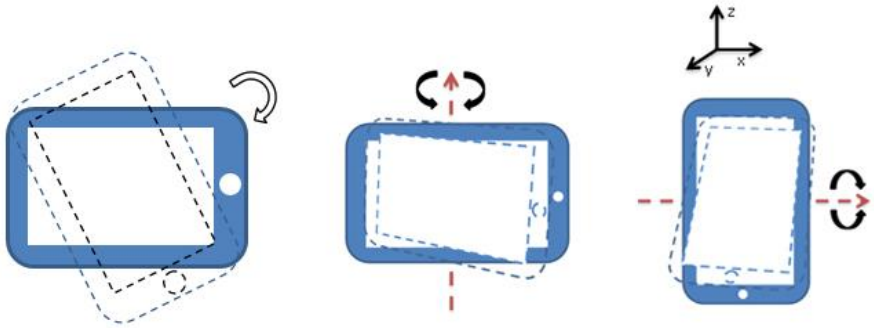


Figure 3-5 Orientation rotations in three-dimensional axis
(Left) Roll rotation (Middle) Yaw rotation (Right) Pitch rotation

As augmented reality games are part of mixed reality environment as shown in Figure 3-2, physical movements in six degrees of freedom which are an amplification of augmented reality inputs are also considered to be part of this mixed reality environment. Although the movements in the physical world have

no actual connections to the other world, they put many impacts to the other world and the feedbacks from the other world also influence the physical world as well as overall player experience. If these are well-coordinated and well-designed, they can create a lot of whole new possibilities to the gameplay and player experience.

Consequently, some metaphors of face-to-face interactions in augmented reality gameplay were created to pursue initial thoughts. There metaphors were designed from a typical setup of augmented reality applications, play-tested with a few game-disciple players, and iterated these processes further in order to display more possibilities of gameplay. These processes observe the overview of face-to-face augmented reality games potentials and concerns. The implementations focused on overlaying of virtual objects per the relative movements of the two devices. The virtual objects are expected to be changed in each metaphor to observe the feasibilities of movements and experience from each metaphor.

Metaphor 1: Simple rigid cube

This is the first and simplest setup of a metaphor among all. The metaphor takes the idea of typical basic augmented reality applications in most augmented reality engines which overlay a primitive object over the marker. By adding relative movements to the objects, it is expected to emerge some feelings of face-to-face interactions. This could lead to the trial of face-to-face interactions experience and give the direction of further metaphors.

Initial setting

In this metaphor, a virtual rigid cube is placed at the middle of two devices. The cube's orientation and position are always the half of the orientations of the detected marker. This is different from a typical augmented reality system where the object would rely purely on one marker's orientations. The setting of this metaphor is expected to interpret the relative movements between the two devices.

The initial setting is shown in Figure 3-6.

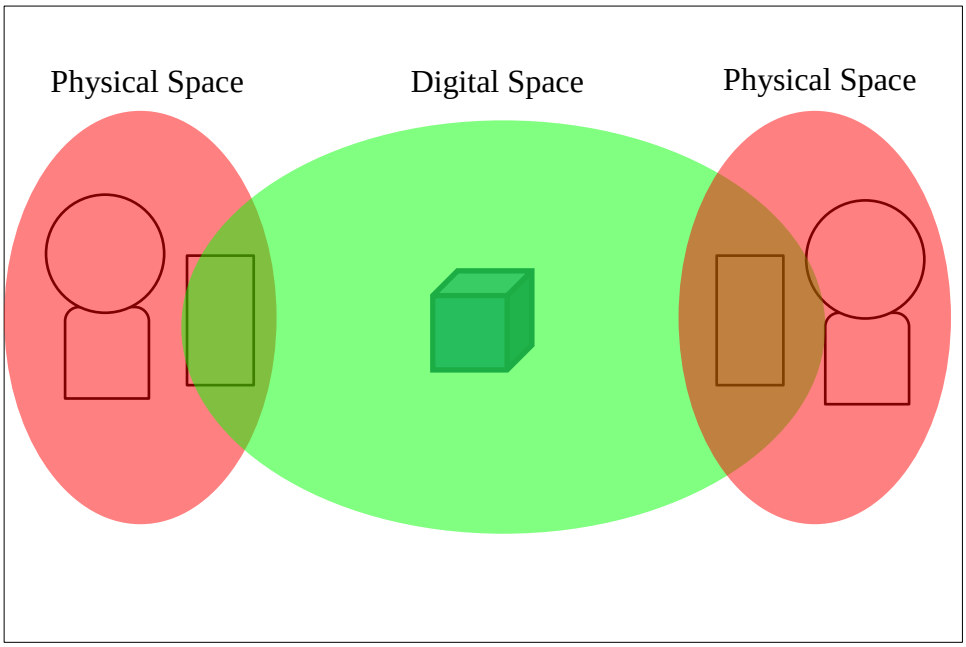


Figure 3-6 Initial setting of metaphor 1

Relative movement interpretations

Moving left or right / up or down: The rigid cube would be in the middle of the two devices. Therefore, it is moved at half of the distances that devices move.

Moving closer to and further from each other: The rigid cube remains in the middle of the two devices when the devices move within the limitation areas

Roll, pitch, and yaw rotations: The rigid cube is rotated at half of the angle when the devices move on each axis.

Metaphor discussion

Since this metaphor is slightly derived from a typical basic augmented reality application setup, participants stated that the experience from this metaphor is like a normal augmented reality system. However, the virtual object is now manipulatable from both sides. It is reported that participants gained a hint of some real physical objects manipulation feeling. However, due to lack of connections between manipulators and objects in sight, the manipulation feeling is slim.

Despite the slim feeling of objects manipulation and typical augmented reality experience similarity, this metaphor suggested the next step to

improve the overlaid images to enhance the hint of objects manipulation feeling in further metaphors.

Metaphor 2: Rigid cube and extendable attached strings

This is an improved version of the first metaphor. In this metaphor, two single strings are appended from the virtual cube to both sides of facing devices. The strings remain connected wherever the devices and virtual cubes are move. Therefore, the string lengths are flexible. This metaphor was created to observe whether the feeling is enhanced when there are visible connections between the manipulated object and manipulators.

Initial setting

The initial setting of metaphor 2 is like the first metaphor. There is a virtual rigid cube placed at the middle of two tablets. The cube's orientation and position are always the half of the orientations of the detected marker in a comparable way to the first metaphor. However, there are two virtual strings appended to the setting with one end attached to the back of device and the other end attached to the cube at the middle.

The initial setting is shown in Figure 3-7.

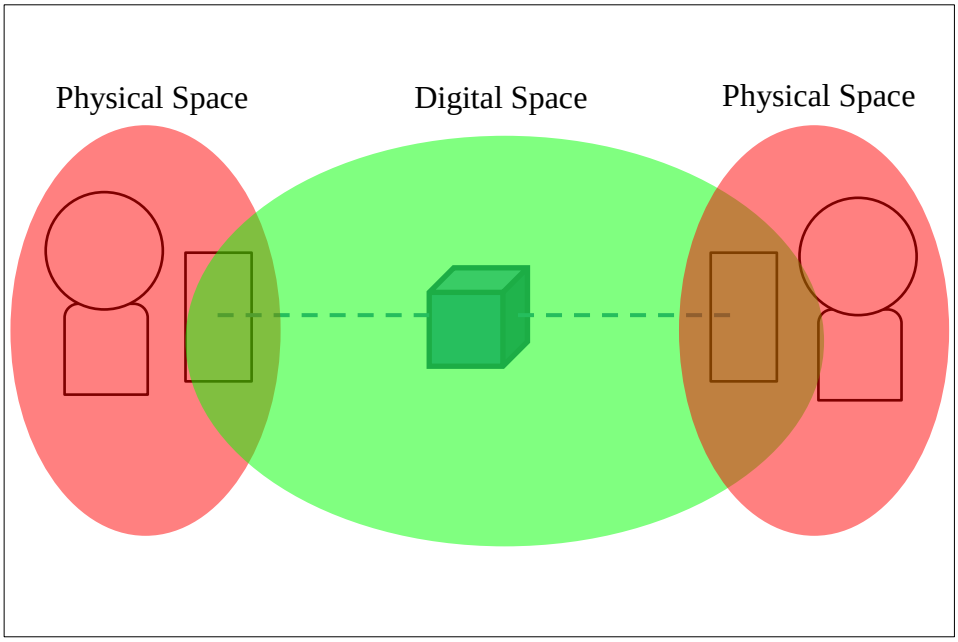


Figure 3-7 Initial setting of metaphor 2

Relative movement interpretations

Moving left or right / up or down: The rigid cube would be in the middle of the two devices. Therefore, it is moved at half of the distances when the devices move while two strings are attached from the cube to the devices.

Moving closer to and further from each other: Since the two lines represent flexible bodies, the strings remain attached from the cube to the back of each device. The length of strings would change when the devices move while the rigid cube remains in the middle of the two devices.

Roll, pitch, and yaw rotations: There is no change at the two strings since it represents a line in two dimensions with no thickness. However, the cube is rotated at half of the angle when the devices move on each axis.

Metaphor discussion

This metaphor was created per the comments from participants who tried metaphor 1. The attached strings were appended with an intention to create a feeling of real object manipulation. However, participants, who also tried the first metaphor, reported that the experience was like the first metaphor with slightly more feeling of real object manipulation. Even though strings were appended to the cube, they appeared as only lines that belonged to the virtual world, not the mixed reality world. It was reported that because the length of the strings was more extendable than the real-world strings, the feeling of the real-world attributes then was lost.

This metaphor could be one of the best examples for having and separating a mixed feeling for users on virtual, realistic, and mixed realistic experience. It could be applied to some kinds of usages in games including the guideline to an interested virtual object.

Metaphor 3: Elastic body and rigid attachments

This is the last metaphor to be tested. Since the previous metaphors fail to deliver a distinctively different feeling from typical augmented reality applications to the users, this metaphor tries to put feelings of more realistic attributes to the virtual world objects. To make the objects feel more towards to the mixed reality world, the elastic attribute was added to the available flexible strings in the second metaphor. Moreover, the strings are increased from one on each side to four. This is expected to help the users feel the elasticity with more strings on each side during rotations.

Initial setting

In this metaphor, there are two main parts of virtual objects. Firstly, there are two rigid rectangles floating on each side, one on the observer (camera) and the other one on the opposite side (marker). Each rectangle moves and pivots per real world positions and orientations on each side. These rectangles represent the controller of strings for each player.

Secondly, the most important part is an elastic body between the two rectangles. This elastic body is represented by four strings connected from a corner of the rectangle on one side to a corner of rectangle on the other side. These strings were initially straight, but they would be changed to curve lines per gestures between the two devices.

The initial setting is shown in Figure 3-8.

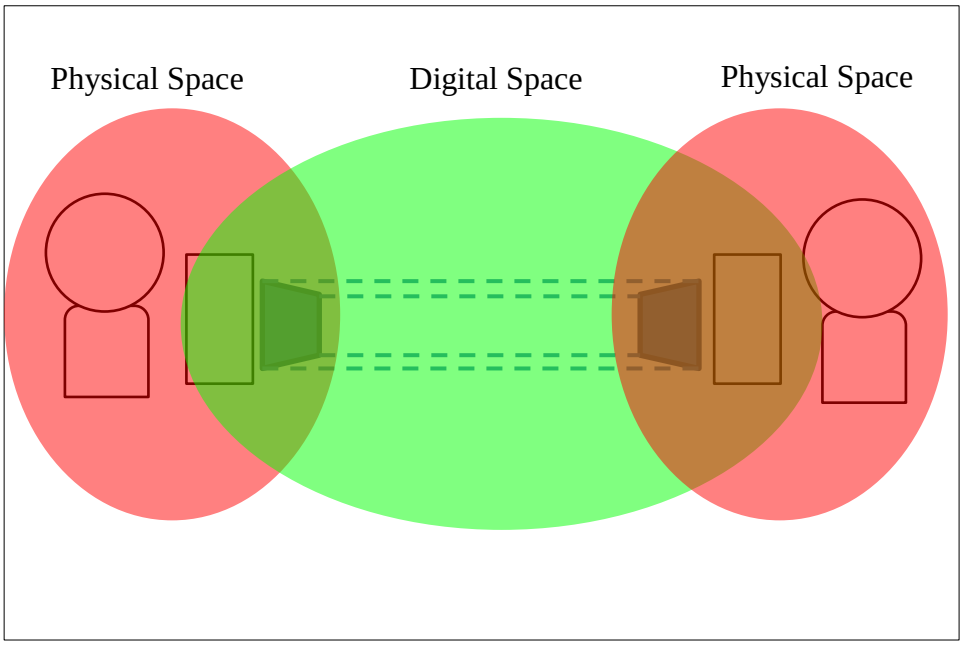


Figure 3-8 Initial setting of metaphor 3

Relative movement interpretations

Moving closer to each other: Since four lines represent an elastic body comparable to the natural physics, the object would be squeezed and pressed from two rigid rectangles because of the shortened distance between the two devices. Four straight lines would be changed to four curve lines, convex out of the centre point, corresponding to the compressive stress. The form of the elastic body would be broken and destroyed when the distance between two devices is shorter than a threshold value of the maximum compressive stress.

On the other hand, all rigid bodies are moved along the two devices of which they are attached to. The forms of the rigid bodies do not change regardless of the shorter distance.

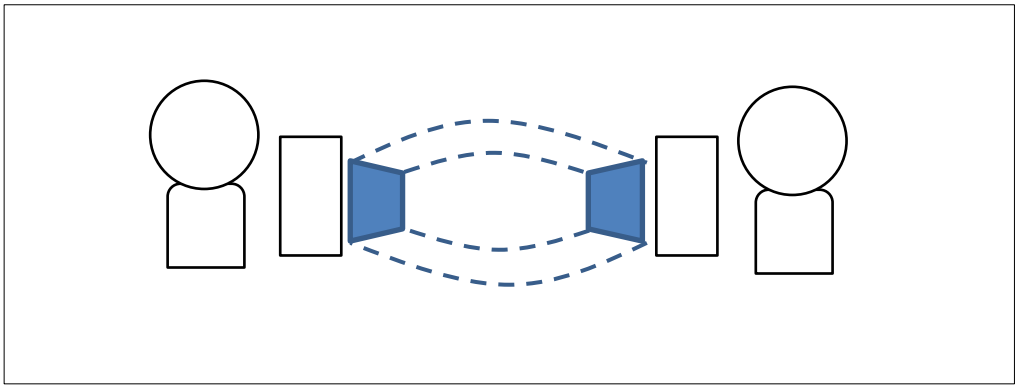


Figure 3-9 Metaphor 3 when moving closer to each other

Moving further from each other: The elastic body in the natural physics would be squeezed from all sides when the object is stretched. This also applies to the elastic object in this metaphor. The four lines would be changed to curve lines, concaving into the centre point, corresponding to the tensile stress. The form of the elastic body would be broken and destroyed when the distance between the two devices is longer than a threshold value of the maximum tensile stress.

On the other hand, like when the two devices are moving closer to each other, all rigid bodies are moved along the two devices of which they are attached to. The forms of the rigid bodies do not change regardless of the length of the distance.

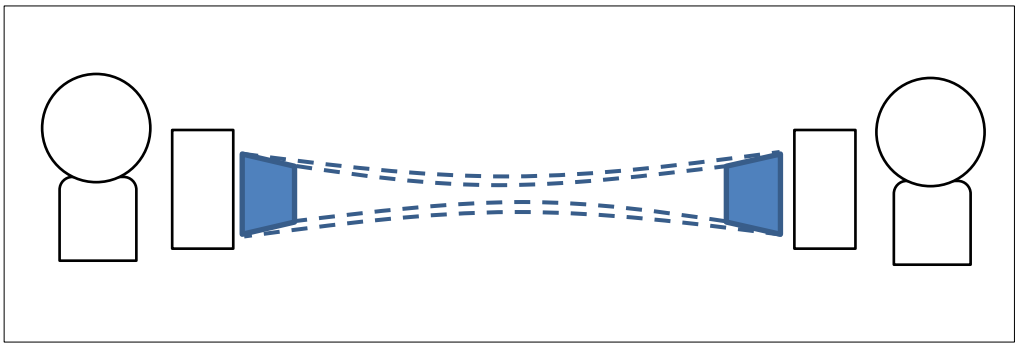


Figure 3-10 Metaphor 3 when moving further from each other

Roll rotations: These gestures cause a rotation around the Y axis in the Unity Environment, which is a normal axis to each device's surface. Apart from rigid bodies, which are moved along the devices they are attached, the elastic body would be affected by shear stress. The four lines would

be twisted corresponding to the movements. The form of the elastic body would be broken and destroyed when the twisted angle exceeds a threshold value of the maximum shear stress.

Pitch rotations: These gestures cause a rotation around the X axis in the Unity Environment. The elastic body would be formed by two rigid rectangles. The four lines would be calculated to be displayed separately corresponding to the positions of the four corners of the rectangles.

Yaw rotations: These gestures cause a rotation around the Z axis in the Unity Environment. Comparable to pitch rotations, the elastic body would be formed by two rigid rectangles. The four lines would be calculated to be displayed separately corresponding to the positions of the four corners of the rectangles.

Metaphor discussion

This metaphor delivers a feeling of a true physical form on virtual objects for users. With the elastic feeling on the strings, it was stated that users can now feel a real-world system on their hands instead of a device. It was discussed among the participants that because the real-world attributes were implemented into virtual objects, the sensation of real objects in their hands becomes apparent. They reported that they experienced a stronger mixed reality feeling than typical augmented reality applications. This is a good start for the improvements on a multiplayer augmented reality system using face-to-face interactions and to provide the most authentic feeling of mixed reality worlds. This metaphor can be applied to many interactions in games, for example, a game of tug of war, which requires twisting strings.

These three metaphors are the starting point of developing the concept of face-to-face interactions to improve multiplayer augmented reality games. They have laid a guideline of interested categories when a face-to-face augmented reality game is developed, as well as their possibilities for their applications. However, they also displayed some limitations that could be considered as conceivable concerns. These will be explored in further sections in this chapter before the study concepts are set at the end of this chapter.

3.2 Feasibilities of face-to-face augmented reality games

The metaphors created in the previous section introduce areas of interest in face-to-face augmented reality games and initiate a lot of potential paths for further

studies, developments, and applications. Simultaneously, they instruct that there are also some concerned limitations which could encumber the process of design and development, or disturb the player experience. The limitations occur due to the arrangement of a marker-based augmented reality setting to the system, along with face-to-face interactions between players. These create constraints on face-to-face augmented reality which is in the mixed reality environment and suggest that several aspects of feasibilities, in both physical and virtual environments, should be brought into consideration.

Benford et al. (2005) proposed a framework of expected, sensed, and desired movements for designing sensing-based interactions. The framework suggests dividing movements into three categories.

1. Expected movements – these are the physical movements in which the users are able and expected to perform per the user, interface, and environment. There are also a set of movements which are less expected to be performed and the movements that are not expected to be performed at all.
2. Sensed movements – these are the movements that can be sensed or measured by the computer using technology to determine and measure them.
3. Desired movements – these are the movements that the users desire to do using the system.

The movements in this framework are overlapped with each other and create the areas for using in design interactions in the system as shown in Figure 3-11.

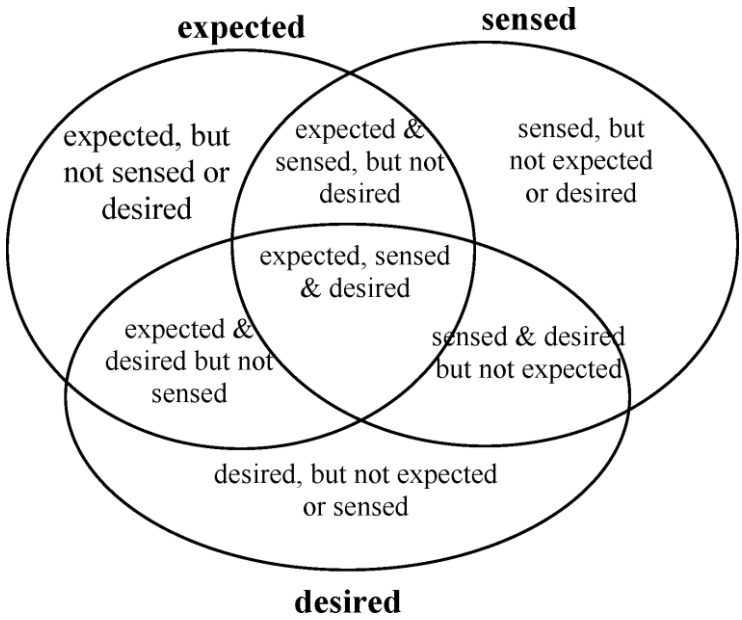


Figure 3-11 Expected, sensed, and desired framework (Benford et al., 2005)

This framework considers the combination between physical movements in the real world, movements that can be detected by the computer, and movements that users want to perform. This framework is, therefore, ideal to be used as the skeleton of face-to-face augmented reality games' feasibility consideration since the face-to-face interactions consist of physical movements and movements which the augmented reality system can detect.

Using this framework, parts of face-to-face augmented reality games to be considered are categorised in each section as follows.

3.2.1 Expected movements

Generally, the expected movements of face-to-face interactions in augmented reality games are the movements in which two users are on the same level of attitude, i.e. on the same floor. Users are expected to hold the device in their hands steadily. Users are expected to perform any movements that cause the device moving in six degrees of freedoms as presented in Section 3.1. However, these movements are limited within their body and environment boundaries. These boundaries should be identified first before advancing into further expected movement declarations.

To begin with, face-to-face actions of two or more users are intersections of a single person's actions and movements while holding a tablet forward. The most related joints to perform a movement in face-to-face augmented reality are hands, wrists, elbows, shoulders, and the head. This creates the ergonomics of face-to-face augmented reality actions. Expected movements of face-to-face augmented reality games are, therefore, within these ranges of the human body e.g. moving left, right, forward, backward, up, down, tilt device left, right, up, down, and rotate device. Users are also expected to sometimes obstruct the camera either intendedly or unintendedly.

The movements that are less expected are the movements that are physically possible, but they are not in the comfortable ranges of motions of the human body. Those less expected movements are the movements in which two users are not in the same level, e.g. one user is on a staircase, the other user is continuously jumping. It is also less expected that a player holds his tablet using only one hand and a few fingers as he will not be able to perform the movements well. The movements like when one user lies on the floor or a device is thrown into the air are also less expected.

The movements that are not expected are users floating in the air and moving freely in six degrees of freedom. Although it is perfect for performing a face-to-face action, it is not physically possible.

3.2.2 Sensed movements

The movements that are sensed by the computer in a face-to-face augmented reality system are the movements that are detectable by augmented reality algorithms. Before discussing further on the movements that are sensed, it is essential to understand what the limitations of augmented reality detection are. Generally, marker-based augmented reality uses a device's camera to track the position and orientation of the marker. Since the camera is always robustly attached to the back of the device, the limitations on the marker tracking which are caused by the camera will certainly affect the overall movements of each user. Apart from the hardware limitations, on the software side, the augmented reality tracking algorithms also put an impact and constraints on the movements. These are the concerns that are not avoidable.

On the hardware side, the specifications of the camera which create the boundaries of augmented reality tracking are the camera's angles of view, focal length, and its resolution. The camera's angles of view produce its view frustum which is the region that the marker can appear and be detected (Sung, Shirley and Baer, 2008). A size of the view frustum totally depends on the camera lens. The wider the angle of the lens is, the larger the size of the view frustum will be.

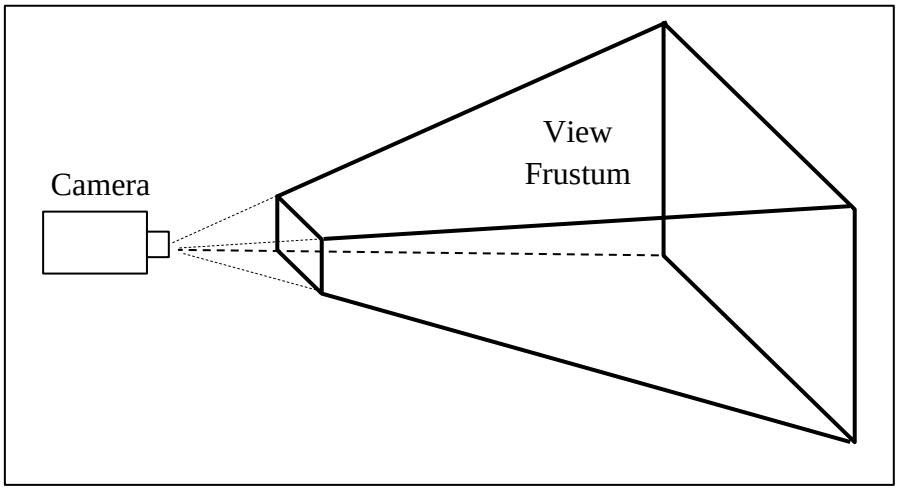


Figure 3-12 Camera view frustum

This contrasts to the camera's focal length. The focal length of the camera determines the size of field of view (Forsyth and Ponce, 2012). The higher the focal length is, the narrower the field of view will be. The size of the field of view directly relates to the size of the object on the screen

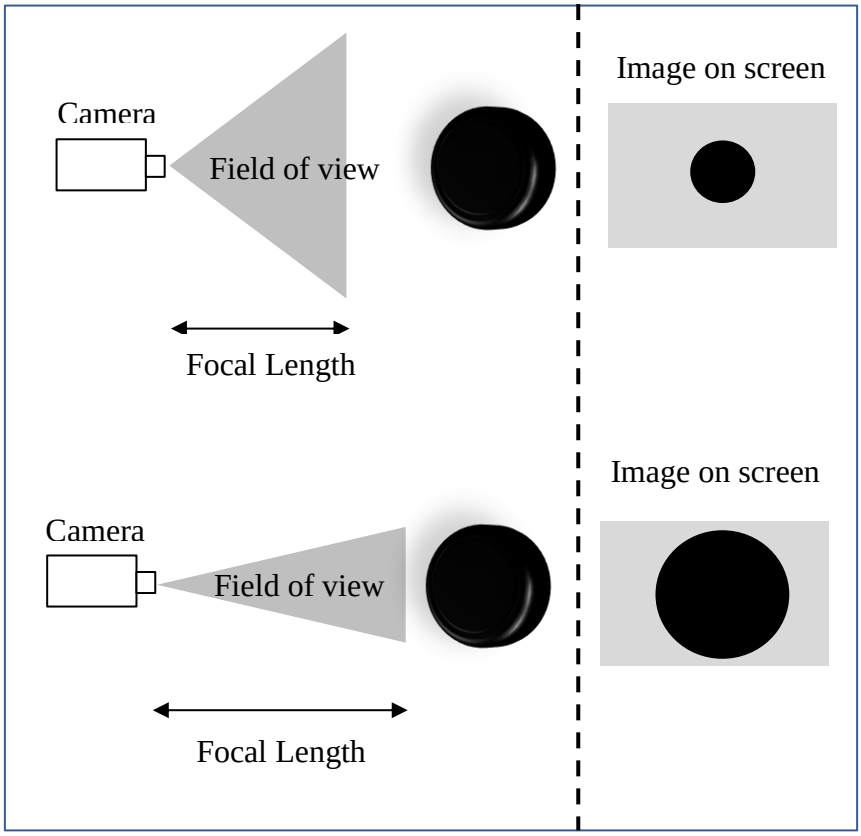


Figure 3-13 Focal length, field of view, and size of image on screen

However, lens resolution is the factor to determines the quality of the image that is used by the augmented reality algorithm (Velho et al., 2009). Although the sizes of the images on the screen are the same, the different qualities of images reflect varied sizes of images that can be processed. The higher the lens resolution is, the better the quality of the image will be.

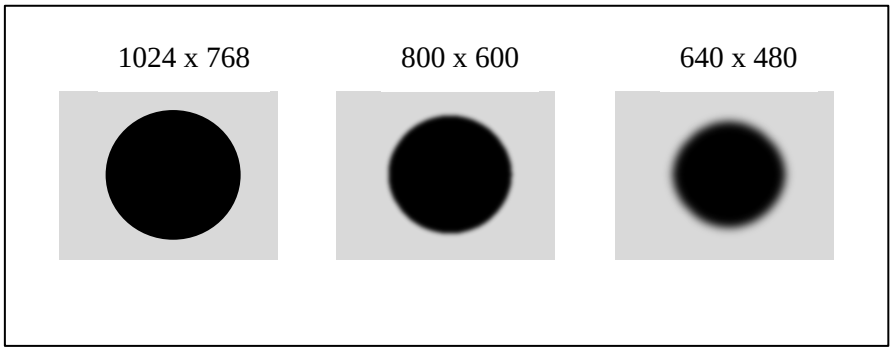


Figure 3-14 Different lens resolution and different quality of images

On the other hand, on the software side, limitations of augmented reality detection depend on detection algorithms. The algorithms may be varied according to each augmented reality engine, but the categories of limitations are generally similar. Typical limitations of a marker-based augmented reality

system have been categorised in my previous study (Towongpaichayont, 2011). These limitations were further tested with a few well-known augmented reality engines, at the time of this study, to deliver actual results of each limitation in order to provide an overview of augmented reality engine feasibilities. The tested augmented reality engines were ARToolkit, Vuforia, and DroidAR. These engines were tested in categories as follows.

Marker detection

The marker detection is performed by computer vision algorithms. The two main steps to detect the markers are to locate the markers and to identify the pattern on the markers. These limitations are the conditions that bring the difficulties to the detection in both steps. For example, it is difficult to locate and find the region of the markers if the camera is too close to the markers. On the other hand, it is difficult to identify the pattern on the markers if the camera is too far away.

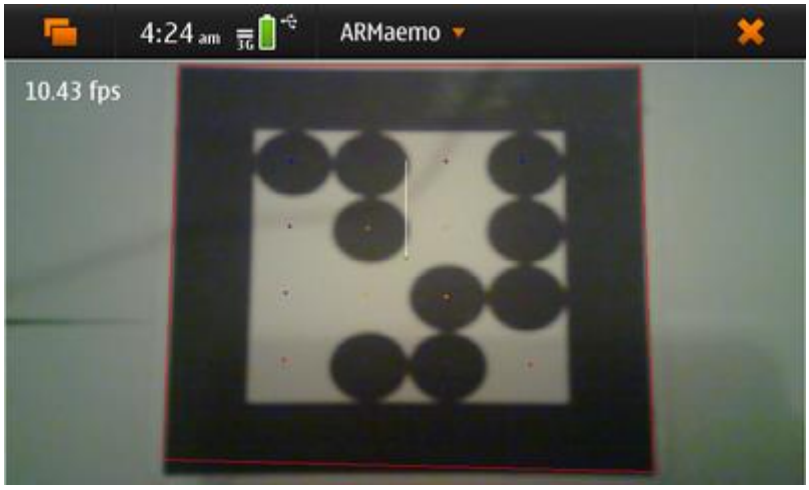


Figure 3-15 Marker detection at short distance

Likewise, it is also difficult to identify markers if the camera's angle of detection is too obscure. The patterns appearing in the scene would be too narrow or too small to identify their features.

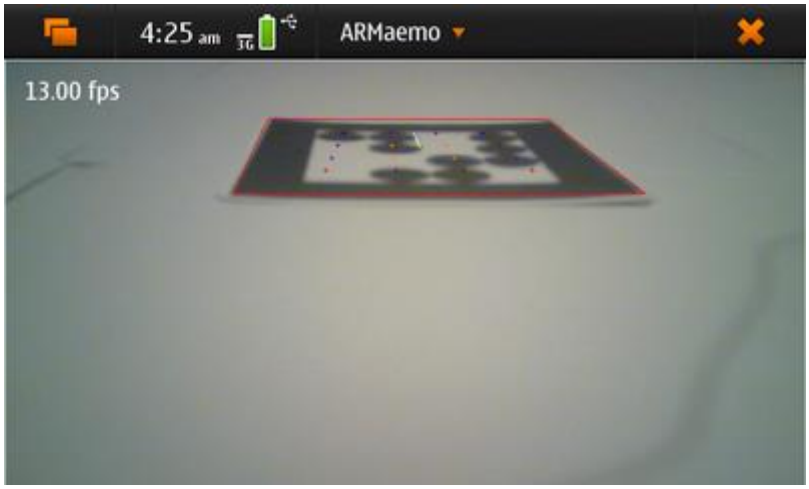


Figure 3-16 The most criticel angle of camera and markers

The actual critical markers detectable distances of each system are different. ARToolkit can detect a marker between 24.50 centimetres and 419.50 centimetres. Vuforia can detect a marker between 4.50 centimetres and 150.00 centimetres. DroidAR can detect a marker between 19.00 centimetres and 214.20 centimetres.

	Minimum detectable distance (in centimetres)	Maximum detectable distance (in centimetres)
ARToolkit	24.50	419.50
Vuforia	4.50	150.00
DroidAR	19.00	214.20

Table 3-1 All engines critical markers detectable distance information

Like critical detectable angles, the actual results are also varied in each engine. ARToolkit can detect a marker at 32.68 degree from the marker plane at minimum. Vuforia can detect a marker at 42.84 degree from the marker plane at minimum. DroidAR can detect a marker at 33.37 degree from the marker plane at minimum.

	Minimum detectable angle (in degree)
ARToolkit	32.68
Vuforia	42.84
DroidAR	33.37

Table 3-2 All engines critical markers detectable angle information

Occluded markers detection

One of the common limitations of marker-based augmented reality systems is that the markers are not able to be detected when markers are occluded by other objects. It happens because the method of finding the marker area in the scene uses a labelling or flood-fill technique. For example, ARToolkit uses a labelling technique to find the region of black squares which imply the location of the markers. When the markers are concealed, these techniques cannot be completed and cause the failure result of detecting markers.

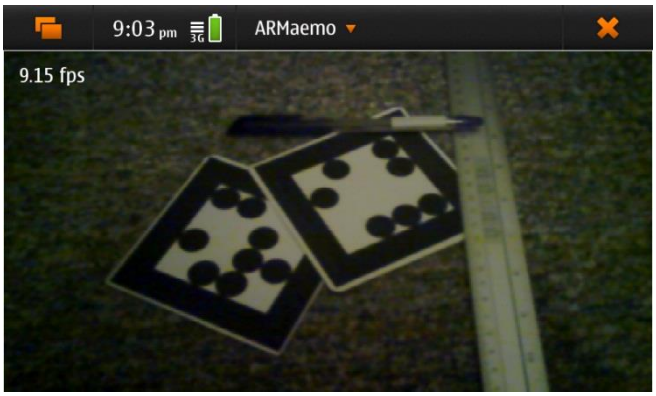


Figure 3-17 Markers with some objects occluded

However, this problem does not occur or occurs in fewer rates in the systems that use line detection or an edge-based detection technique to detect the region of the markers as Martin Hirzer explained in his article about an algorithm of edge-based marker detection in 2008 (Hirzer, 2008) and his algorithm was implemented in C++ by Corné den Otter and Reinder Nijhoff of Infi Company in 2010 (den Otter and Nijhoff, 2010) to present the practical aspect of this method in order to overcome the occluded marker detection problems.

The occlusion test was performed in different edges by concealing markers at every 5% (0.75 centimetres) to identify whether the virtual object is stable and at the right orientation. The test is performed until the object disappears from the screen.

ARToolkit presents a very good result of augmentation when concealing the marker at 5% from the top or bottom edges. However, when the marker is concealed at 10% and 15% from the top or bottom edges, the virtual object position changes and it is not at the right place. It is placed at the centre of the remaining unconcealed marker. However, after 20% (3 centimetres of 15 centimetres) is concealed, or around at the inner black border of the default marker, the virtual object totally disappears. Meanwhile, when the marker is concealed from the left and right edges, ARToolkit shows a satisfied result at 5% and 10%. At 15%, the error of position appears like the results when covered from the top or bottom edges. Resemble to the top or bottom edges concealing results, the object disappears when the marker is covered at 20%.

In Vuforia's case, the results of covering from either the top, bottom, left, or right edges are similar. The system shows an impressive performance when the marker is covered with no error of positions and orientations occurs. The object stops appearing when the marker is covered at 65% from the edges (9.75 centimetres of 15 centimetres from the top or bottom edges and 13.65 centimetres of 21 centimetres from the left or right edges).

DroidAR stops detecting markers at the 5% marker concealing (0.75 centimetres of 15 centimetres) from every edge while the system performs the augmentation very well when the marker is covered less than 5%.

	ARToolkit	**Vuforia**	**DroidAR**
From Top Edge			
5%	O	O	X
10%	O with errors	O	X
15%	O with errors	O	X
20%	X	O	X
-----	-----	-----	-----
60%	X	O	X
65%	X	X	X

From Left Edge			
5%	O	O	X
10%	O	O	X
15%	O with errors	O	X
20%	X	O	X
-----	-----	-----	-----
60%	X	O	X
65%	X	X	X
From Bottom Edge			
5%	O	O	X
10%	O with errors	O	X
15%	O with errors	O	X
20%	X	O	X
-----	-----	-----	-----
60%	X	O	X
65%	X	X	X
From Right Edge			
5%	O	O	X
10%	O	O	X
15%	O with errors	O	X
20%	X	O	X
-----	-----	-----	-----
60%	X	O	X
65%	X	X	X

Table 3-3 All engines occlusion test information

These are typical concerns of the augmented reality marker detection algorithm. There are also minor concerns such as light conditions and the number of detecting markers. However, the main concerns are these critical positions and the orientations of detection. These critical values create a detection pyramid which are the area that the marker can be detected. The size of the detection pyramid relies on the critical detection angles. The lower the critical detection angles from the marker plane are, the larger the size of the detectable area will be.

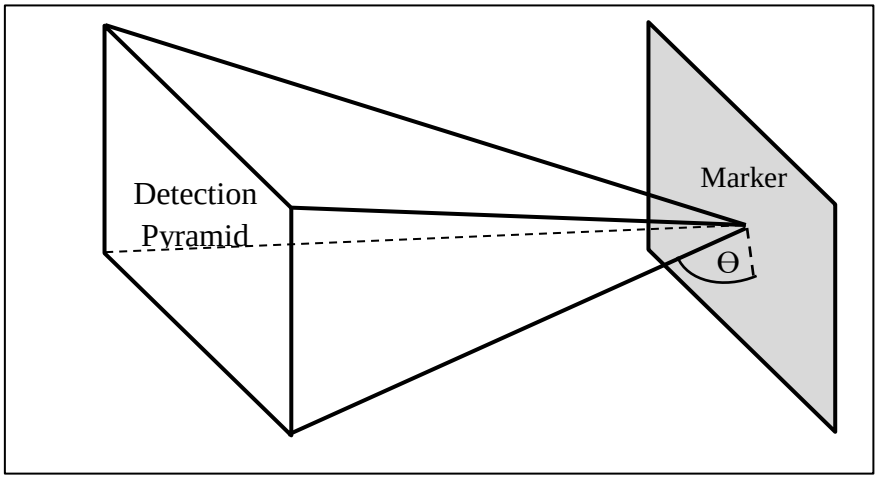


Figure 3-18 Marker detection pyramid

Size, quality, and occluded area of an image on the screen are other concerning attributes of augmented reality algorithms. Size and quality depend on, apart from camera lens specifications, the distance from the camera to the marker. These create the minimum and maximum detection. Finally, the detection on the occluded marker is the attribute to reflect the ability of augmented reality algorithms. These also depend on the augmented reality detection and tracking algorithms.

Combining the limitations from hardware and software sides, there is an area of the intersection of all limitations. This is the ‘detectable area’ of augmented reality detection.

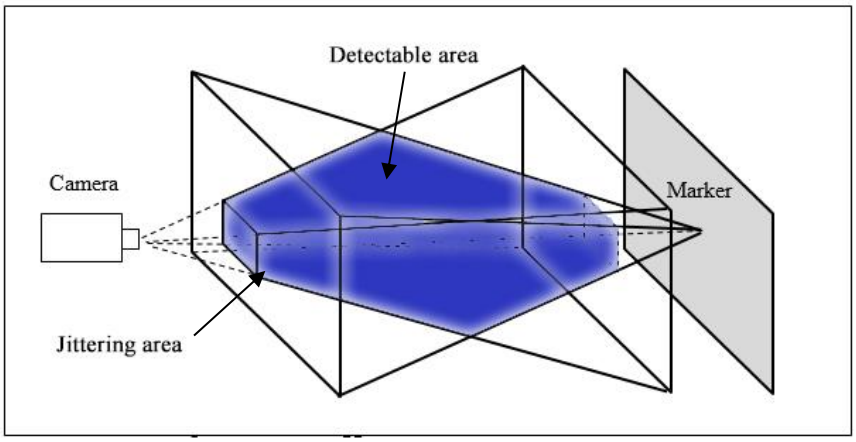


Figure 3-19 Augmented reality detectable area

If the camera and the marker are within this detectable area with a suitable environment, the marker will be detectable and augmented reality algorithms should be working in theory. Any movements can be performed if the movement does not cause the camera or the marker to move out of this detectable area. However, due to the limitations of an augmented reality process, it is possible that augmented reality does not perform well near the edge of the detectable area and causes an unstable detection which leads to a jittering augmentation.

Within this detectable area, it is up to the lens resolution and occlusion of the marker to determine if the movement can be detected, tracked, and translated into useful information to the augmented reality system.

Therefore, in theory, this detectable area is the area that the movements can be sensed when considering each movement individually. However, when considering face-to-face interactions, the area that augmented reality can perform the detection is shifted according to the movements of both devices, as shown in Figure 3-20.

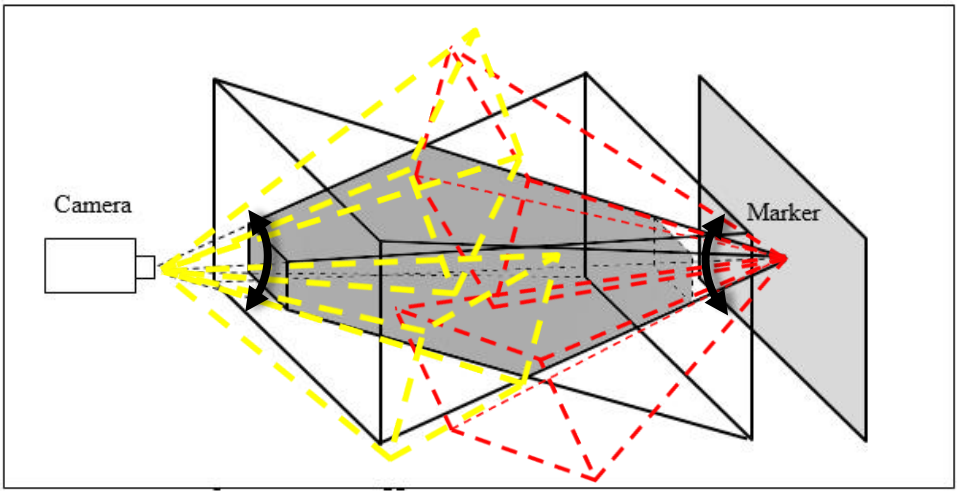


Figure 3-20 Movements of both devices change the detectable area

Furthermore, some interactions can cause the sensed movements to be totally different from the physical movements. For example, when one user is moving left, and the other user is moving right at the same speed. The system senses that there is no movement at all since both devices are moving in the same direction.

In summary, sensed movements of face-to-face augmented reality games are the relative movements between two players which are the combinations of individual movements within the detectable area. This results in a good detection on augmented reality algorithms, but interpretations of relative movements are not necessary to be sensible for the physical world.

3.2.3 Desired movements

Finally, the desired movements of face-to-face augmented reality games are the movements which occur from the relative movements in each player's point of view. For example, if the opponent is moving backward and the player desires to keep the movement as a standstill, the player must move forward to catch up with his opponent's movement.

Since the desired movements in this case are the relative movements between the two facing devices, it is important for designers to consider movements on both sides to create a set of realistic movement requests to develop a pleasant experience on augmented reality games as shown in the list of metaphors in the previous section.

Considering all points in the expected, sensed, and desired framework, it is reasonable to indicate that the feasibilities of face-to-face augmented reality games are the area that three sections intersected. This is a guideline for designers who design face-to-face augmented reality games in the future. The game should lay on this intersection area of expected, sensed, and desired framework.

3.3 Designing workshop: Exploring possibilities of face-to-face augmented reality games by a practical approach

Feasibilities of face-to-face augmented reality games have been discussed under an expected, sensed, and desired framework in the previous section. It established limitations of physical movements in the physical world, the augmented reality hardware, and algorithms in the virtual world which created feasible space for face-to-face augmented reality games. Within these feasibilities, there are certainly possibilities to create various kinds of gameplay as parts of these have been shown during metaphor exploration. The possibilities in face-to-face augmented reality games are now being explored using a designing workshop pattern. By using this practical approach, it is expected that many kinds of promising face-to-face augmented reality gameplay can be extracted, together with observations on what and how designers consider when designing a face-to-face augmented reality game. By the end of this section, there will be a few potential face-to-face augmented reality game examples presented, along with a discussion on findings during face-to-face augmented reality game designing processes.

3.3.1 Designing workshop overview

When a series of face-to-face augmented reality game metaphors were designed and developed, many potentials and novel experiences were displayed. They were thought-provoking to seek for other further promising game design examples. Several face-to-face augmented reality game examples are in need to be designed and displayed to show the possibilities of this setting of augmented reality games. However, game design is one of the areas which has no specific pattern to achieve. There are many approaches in game design and there are a lot of templates which have evolved over decades. One approach to the face-to-face augmented reality game designing process is to design gameplay mechanics based on the relative movements and constraints like the metaphors design. However, since face-to-face augmented reality is a novel setting in the augmented reality field and it is a specific kind of gameplay, it is difficult to design a game on it without some knowledge beforehand and it causes a limited perspective on the design. The augmented reality game design exploration starts

with gathering some veterans in the related fields to brainstorm and put a guideline for the next path of game design. After a pilot brainstorming session was conducted, the result was satisfied and practical. After that, several numbers of brainstorming sessions were conducted, and they became more and more structured. By using the pattern of structured design workshops with participants who have expertise in either game design or augmented reality fields, the results which were gameplay designs along with designing process were produced from several aspects and it fulfilled the intended goals to explore the possibilities of the topic.

Design Workshop Outline

The pattern of game design workshops should comfort the designing procedure of face-to-face augmented reality games which are unusual for some of the designers as they are dissimilar to typical types of games, according to the pilot study. From Rules of Play (Tekinbaş and Zimmerman, 2003), there are several designing processes that could be derived and adapted to the suitable designing process for face-to-face augmented reality games. One is to transform the designing process into a designing game (Hornecker, 2010). The designing game that has been widely used lately is a card game which is tangible and easy to define necessary components in games (Lucero and Arrasvuori, 2010). In this series of workshops, based on a game design pattern in Rules of Play (Tekinbaş and Zimmerman, 2003), the process would be easier and imaginable for game designers when designing a game from a scratch on an unfamiliar platform by specifying each game design components that are necessary for the game itself which the designers are already familiar with - for example, roles of players, player's objectives, etc. The game design components are the core elements of each game. Therefore, if each component is pre-defined, it is imaginable for game designers to focus only on the creativity for the game, which could result in a good outcome with face-to-face augmented reality games. For these reasons, all game components were transformed into a deck of cards. It is expected that at the end of the series, potential example game designs of face-to-face augmented reality games should be achieved.

Game design components

The problem of game design is to determine which components should be specified for a design process. The components that are decided to be used are conspired from the elements of games in several pieces of game design literature - Rules of Play (Tekinbaş and Zimmerman, 2003), Pattern in Game Design (Bjork and Holopainen, 2005), and Game Architecture and Design (Rollings and Morris, 2004). The components used in this workshop are as follows.

1. Fixed rules

   The fixed rules are the rules that are defined beforehand to outline the characteristics and limitations of the game. These rules will be the highest level of the designing process which will keep all designers on track.

2. Type of play

   This is the type of augmented reality that is going to be designed. It will define the size of gameplay and the overall setting of the game. There are two types of play in the workshop. The first one is 'face-to-face around table'. This type of gameplay is the game that gathers the players around the table. Normally, the players do not move much, and the concentrated parts of the game are few. The other type of play is 'running around'. This type of gameplay is the game where the players relocate their positions a lot. The concentrated parts of the game are normally placed in several locations.

3. Players and system roles

   This component specifies the roles of the players and the system to elucidate what the players and the system would do in the game. It is possible for the players and the system to possess more than one role at the same time. For example, the system can relay messages which will only be delivered to the players and are not involved in gameplay. It can guide what the players should do occasionally but will not be involved in gameplay directly. The system can interrupt the player's actions occasionally depending on gameplay. One of the players may gain all abilities and constraints like other players. The system may pose its actions either as cooperative or competitive to other players. Lastly, the system can take the role of an outstanding player or a boss character which will have outstanding abilities and much less constraints compared to the other players. Like the previous role, it may pose its actions either as cooperative or competitive to the other players.

4. Social mechanics

This component defines the relationship among the players, and the relationship between the players and the system which will outline the social scenario in the game. There are plenty of social mechanics. The social mechanics which are listed below are used in this design process: -

- Competitive / Race: Players are assigned to race to achieve something before the other players.

- Conflict: Players are assigned to conflict with each other in the game which could be verbal or physical. The conflicts remain until the end of the game.
- Elimination: Players are assigned to eliminate the other players individually or in group until the winning conditions are achieved.
- Cooperation: Players are assigned to cooperate with each other to achieve the winning conditions, in which one or many players could win.
- Betrayal: Players are assigned to cooperate with each other initially and betray the others as the game progresses.
- Individual rewards / penalties: Players are assigned to compete to achieve a reward or avoid a penalty.
- Shared rewards / penalties: Players are assigned to compete to achieve shared rewards or avoid penalties.

5. Group activities

This is to specify what the players will do to process the game. Group activities outline the activities which the players do together to process the game. The group activities which are used in this design process are listed below: -

- Team play: Players must play as a team to process the game.
- Alliances: Players must play individually but maintain good relationships and mutual agreements with other players to process the game.
- Roleplaying: Players must play a role, which could change as the game processed, to process the game.
- Constructive play: Players must play to construct an object to process the game.
- Player decided results: Players must make an individual or mutual decision to process the game.
- Trading: Players must trade resources with each other to process the game.
- Bidding: Players must put resources on bidding in order to process the game.
- Social interactions: Players must interact with each other, verbally or physically, to process the game.

6. Game mastery

This is to specify what the players should master to take advantage in the game.

7. Goals

This is to specify what the players should aim for in each round of the game. It may be different on each player and there might be more than one for each player. Goals are the objectives of the action of each player. There could be one or more goals for each player. Goals which are used in this design process are listed below: -

- Gain ownership: Players should gain ownership of something in the game.
- Overcome: Players should overcome the other players in the game in any terms.
- Stealth: Players should put themselves in stealth and not to be detected by the other players or the system.
- Capture: Players should capture and hold something in the game.
- Rescue: Players should rescue something in the game.
- Eliminate: Players should remove something from the game.
- Evade: Players should escape from something in the game.
- Conceal: Players should cover their resources or information from the other players or the system.
- Race: Players should race to gain something in the game before the other players or the system.
- Collection: Players should collect something in the game.
- Guard: Players should protect something in the game from the other players or the system.
- Survive: Players should concentrate on their survival from threats in the game.
- Traverse: Players should relocate themselves in the game.
- Gain information: Players should gain information from the other players or the system.
- Gain competence: Players should gain experience in the game from their actions.
- Exploration: Players should explore something in the game.

Design Workshop Structure

The components of the game are transformed into a deck of cards to perform a series of game designing. As mentioned before, the design workshops were planned to present varieties of face-to-face augmented reality games by focusing on using creativities to answer the questions rather than building something up from scratch without enough familiarity. These require a structured execution to put every bit together. The workshop structure for 150-minute time duration is as follows.

Introduction session – 30 minutes

The purpose of this session is to introduce the current prototype system, its concept, and its guidelines for the implementations. It is also to introduce the purpose of the workshop and the workshop schedule. After that, the prototype system is introduced. Participants will have an opportunity to try the prototype system. Afterwards, the methodologies used in this workshop will be explained in detail for the participants to be ready for the next stage of the workshop.

Specify game design components – 30 minutes

The purpose of this session is to prepare the foundation information of game designing to be used in the entire workshop. Each game component will be divided into categories which are represented by a deck of cards. Some components which are Type of Playing, Social Mechanics, Group Activities, System Role, and Game Mastery will be picked randomly while the goal of the game will be chosen by the participants secretly one-by-one. These build the main components of the game that will be designed to limit but ease the participants to focus on using their imagination in game designing rather than worrying about designing a game with technology and a setting that they are not familiar with. These components are pinned up on a big board to be the foundation of this workshop.

Brainstorm – 30 minutes

The purpose of this session is to ask the participants to consider any existing games that satisfy some or all game components that are selected. This is expected to familiarise the participants with the current situation and use this opportunity to expand the imagination of game designing. Various gameplays are expected to be introduced in this session, which might be also some good practical games to be developed in the future. After that, there will be a 15-minute short break to refresh and wrap up.

Game Design – 45 minutes

After the first discussion, the participants should be able to refine their ideas and imagination in game design with the current setting of the game components. In this session, the participants are asked to pick one game to further design by filling in the missing game components which are player roles and winning conditions. With only a few components left, this should be feasible for the period given.

Discussion and wrapping up – 15 minutes

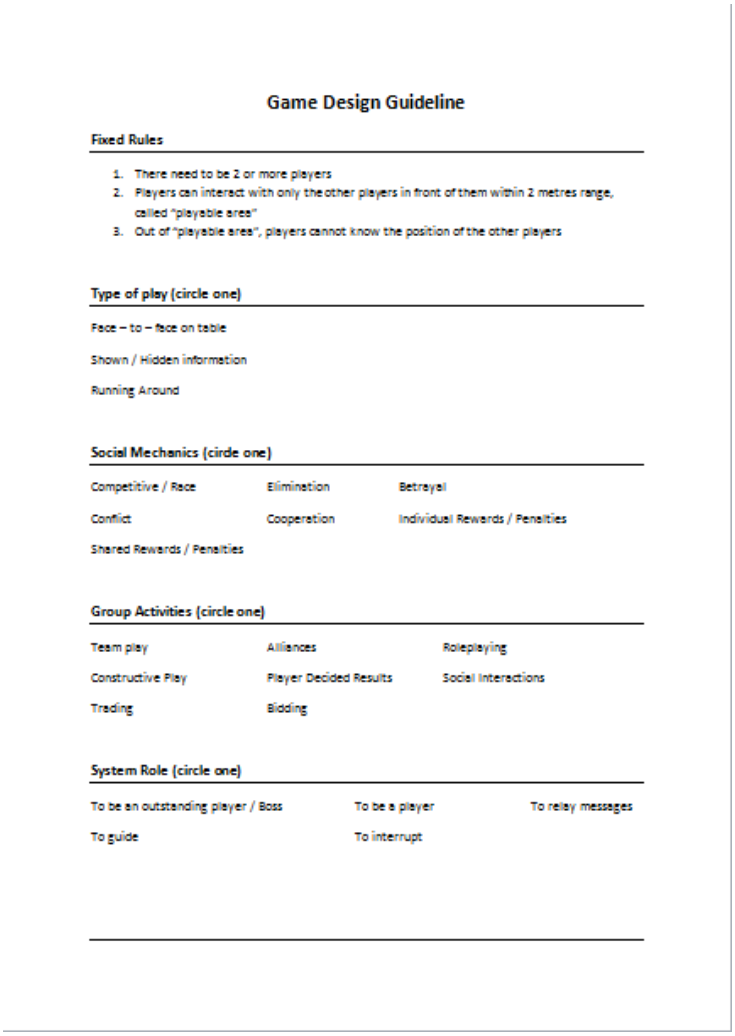
In this session, a conclusion will be drawn, and a number of questions will be asked to all participants for their thoughts about the technology and applications on games.

3.3.2 Actual workshop progressions

There were a few workshops conducted in total using the structure in the previous section. The results of all the workshops will be summarised in this section with separate sessions to present the thinking process of the participants from the beginning to the outputs.

Introduction session

Each workshop started with an introduction to game component cards. Each category of the cards was explained briefly to the participants before approaching the cards selection session. After that, before starting the process, the guideline document was introduced to all participants in each workshop. This guideline document consisted of three pages of all game components used in this workshop to ease participants in terms of keeping tracking of the information and focusing on the designing tasks. A sample of guideline documents is shown below.



Game Design Guideline

Fixed Rules

1. There need to be 2 or more players
2. Players can interact with only the other players in front of them within 2 metres range, called "playable area"
3. Out of "playable area", players cannot know the position of the other players

Type of play (circle one)

Face – to – face on table

Shown / Hidden information

Running Around

Social Mechanics (circle one)

Competitive / Race	Elimination	Betrayal
Conflict	Cooperation	Individual Rewards / Penalties
Shared Rewards / Penalties		

Group Activities (circle one)

Team play	Alliances	Roleplaying
Constructive Play	Player Decided Results	Social Interactions
Trading	Bidding	

System Role (circle one)

To be an outstanding player / Boss	To be a player	To relay messages
To guide	To interrupt	

Figure 3-21 The first page of game design guideline documents

The fixed rules were explained to participants.

1. This game must consist of two or more players.
2. Players can interact with each other within two metres.
3. Out of two metres range, they will not know each other's position.

The first rule is the purpose of the game as it will be a multiplayer game while the latter rules are due to technical limitations as expressed earlier in this chapter.

Specify game design components

In this part, the main game component cards were selected. These were the basis of game design outcomes of this workshop. The selected cards were pinned on the flipchart on the wall which contained updated information of the designing process all along the workshop to help the participants to focus on designing a gameplay.



Figure 3-22 The guideline flipchart was attached on the wall / the flipchart being completed

The game components were picked as the designing game rules indicate. For example, “Type of Play”, “Social Mechanics”, “Group Activities”, “System Role”, and “Game Mastery” were picked randomly, while “Goal”, which could indicate a type of gameplay, were picked intentionally by each participant. Each participant picked one “Goal” card per person secretly and another “Goal” card was picked randomly. Once all “Goal” cards were shown, all participants must discuss and decide a “Goal” card to be removed. This was the process to adjust the mind sets of all participants together before the whole design process began. Sometimes, participants chose Goal cards to comfort the design process later. However, there were also some workshops that participants decided to challenge themselves by choosing Goal cards which did not comfort each other. This totally depended on an agreement between all participants and it did not have a significant impact on the end results of the workshop.

Brainstorm

The purpose of this session is to familiarise participants with the conditions of game design picked by cards and to spread the ideas which could be materials for the actual game design process. For this session, there were differences in detail in each workshop, but the beginning points were similar. Generally, participants discussed together to gather several games that shared the game components that were picked in the previous session. This procedure was to comfort the real game design process and to help participants feel more comfortable with the game components by sharing their ideas. However, this process did not involve any brainstorming. In one workshop, participants started with linking some of the picked cards that they could present an existing game with. For example, they presented “Lie Dice” in which the players could take turns, hide their dice, and declare how many dice showed up on the declared face, whether it was a lie or not, and other players had to see through the lie. This conspires with some, but not all, goals and group activities. In the same workshop, they also tossed the idea of Concert Game where the players were from different bands trying to perform the concert in their own way without letting the other players know what instrument they were playing. This satisfied the same goals as Lie Dice but satisfied how players mastered the game instead of the group activities. On the other hand, in another workshop, participants started with one game component that they felt comfortable to work with and expanded the idea from this component. They started with the type of play “Face-to-face game around a table” in which they could raise some existing fighting games using markers on the table and the players could control their own character in the game to fight. After that, they linked this game with the prototype using relative movements and strings to control the character instead of touching the screen. They then observed any picked cards that could be added to this game, for example, “Survive” goal or “System as a player” system role.

They continued adding these components until they were stuck or satisfied and advanced to another game in a similar fashion.

Despite these different approaches, interestingly they eventually stumbled into similar problems – the limitations of the system and face-to-face augmented reality games. In one workshop, in which the "Rhythm-Based" was drawn, the participants found that it was difficult to link this card with the others. They discussed that the major problem of augmented reality with the Rhythm-Based game might be the synchronisation between devices. This was because augmented reality relied on the detection algorithm which could contain some delays and cause a problem on the Rhythm-Based game. This led to the other similar limitation issues such as only a few players could be synchronised by using the vision from the camera or the responsive time which would cause the problems on designing an augmented reality game. While in another workshop, the participants found that there were no network connections between devices which meant that each device would not know the state of the other devices. Furthermore, the device recognised the relative positions of other detected devices but could not acknowledge the global positions of all devices, which could be a feature of a game or a limitation. These findings revealed some interesting points which will be discussed in the upcoming section.

Because of these constraints, there were some leniencies in some workshops to ease the design to be within the workshop time limit. For example, there were network connections allowed in one workshop. However, participants in those workshops were reminded that the constraints from picked cards should be the primary concerns. With these leniencies, the participants appeared to be more comforted to toss out ideas in the brainstorm instead of focusing on the limitations. For example, in the workshop that picked the "Rhythm-Based" card, they raised the "Johann Sebastian Joust" game, which is a PlayStation game in which many players have their controllers without a screen. Each player played music and moved around trying to make the other players move out of the rhythm to eliminate them without being eliminated. Moreover, the rhythm of the background music was the controlling feature of the game where it could control the pace of the player's movements, which would subsequently control the pace of the game itself. These linked Rhythm-Based card with Eliminate goal and Social Interactions group activities and this game could easily be converted to a face-to-face augmented reality game. The participants suggested this without any concerns on the constraints, which benefited the brainstorming session. There were many other games that were mentioned e.g. "Risk", "Pandemic", "Pong", etc. which were great materials for the actual game design session.

Game Design

This session often blooms the results from the previous brainstorm session. The participants normally used discussions in a brainstorm session as their materials to start designing a game. As this session was placed after a short break, they had opportunities and time to rethink about what they learnt and discussed from the brainstorm. Sometimes, they casually talked with each other over the break time in the common gathering point like the coffee machine. In one workshop, the participants quickly introduced a game design immediately after the break as they talked about interesting points during the brainstorm session and surface a game design within a fifteen-minute short break. However, there was also one workshop where the participants still could not provide any game designs until the last ten minutes of the session. These varieties might result from the difference in disciplines of each participant. Anyhow, all participants still used the materials from the brainstorm session to design the final game outputs in every workshop.

Discussion and wrap up

In general, two main topics arose from the discussion among the participants during their workshop. Firstly, they discussed about the methodologies used in the workshop. They talked about the efficiency of the methodologies and how they could be improved in the future, for example, adding a brief description on the card, or using colours to separate card categories. Secondly, they discussed in part of augmented reality game limitations and how these limitations affected the game designing. This hugely benefited the research topic of this thesis, also put impacts on establishment of area of study in the upcoming section. These points will be discussed later in Section 3.3.4.

3.3.3 Workshop outputs

The final output of this workshop was a game design that satisfied all selected game components, if possible, or most of them. In this series of workshops, there were three game designs produced. The first game is the game that imitates the factory processes into one single playing room. The second game is a game that imitates a party game called ‘Hot Potato’. The last game is a tower defence game. These games were briefly outlined during the workshop and were redesigned in detail after the workshop.

Red Army Factory Game

Game concept summary

This game aims to be played in a closed space room and transform this playing room into a factory. Players are required to be the workers of this factory and cooperatively operate the process of this factory through the public markers that represent each working station of the factory.

This game can be played with two or more players. Each player has a tablet to play this game. Each tablet has a marker attached to the back of the tablet. There will be additional markers elsewhere, for example, on the ceiling, on the table, on the wall, etc. to represent the working station of the factory. There is also another PC which is used as the server where every tablet is connected as a client.

This game will be played in turn. On each turn, there will be a signal from the server sent to each tablet telling them what to do. Each player needs to find the marker to process, either at the back of another player or somewhere else.

The game will run faster every single turn. The player who cannot find another marker to process the game in time will lose his life. There are three lives for each player to lose and he will be immediately eliminated if he loses all his lives, which means the other players need to cover the rest of the operations. After the last person is eliminated, the game will end and the results will be scored in each category, for example, the best long run, the best cooperative, etc.

The game world

As this game is a multiplayer augmented reality game, the game will consist of two main parts of the game world, which are the physical world and the virtual world. In the physical world, the system contains a number of tablets for each player and one desktop computer as the server. There are a number of markers to control the game flow. A number of markers will be attached to the back of each tablet to represent the identity of each player and the rest of the markers will be securely attached to the other places in the playing room to represent the working station of the factory.

In the virtual world, the augmented objects are the working stations and working objects. This could be a supply in the supply chain where the players are required to operate with the tablet's physical movements. Objects can be transferred from a working station to a worker, a worker to a worker, and a worker to a working station.

Game control

This game is controlled by each player's tablet. The player will use his tablet to point to another marker when there is a signal and perform the movements according to the server instructions. This does not require a touchscreen to process the game.

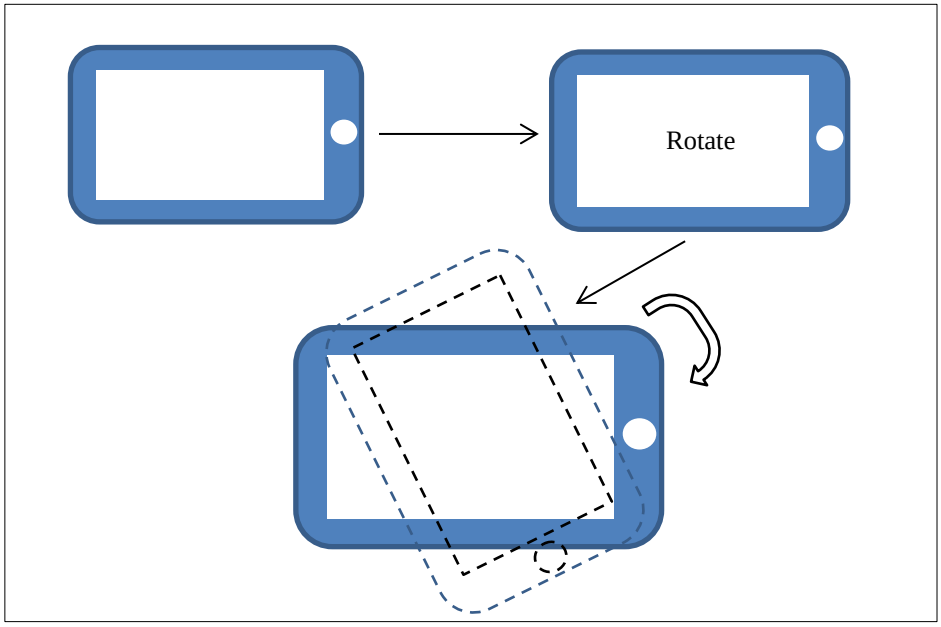


Figure 3-23 Red Army Factory game – Game Control

Core augmented reality mechanism

The mechanism and the interaction between each marker depend on the server. When the player receives a signal, he will find a necessary marker to process the game and perform a face-to-face movement with that marker according to the server's order. The game is processed according to the game states and the marker being processed.

Technical configuration

The game is set with a marker attached to the back of each tablet and a set of markers attached somewhere else in the playing room. There will be also a separate server and each tablet will be counted as a client and connected to the server. The activities that happen in the game will be all operated by the server. The information will be sent to the client.

The server will decide what operation each player should perform and send the instruction to the player. The players are required to perform according to the instructions in time. Whether the operation is successful or not, the client will send the information back to the server and the server will operate the received information for the next move until the game ends.

Holding a Bomb Game

Game concept summary

This game takes the concept of a party game into an augmented reality game. The concept idea includes a bomb that a player is holding. That player needs to send the bomb to another player before the time runs out. The ideal state of this game is that no player except the bomb holding player knows who has the bomb. This makes the game more fun and exciting.

This game consists of six or more players gathering around the table. Each player has a tablet to play this game. Each tablet has a marker attached to the back of the tablet. There can be additional markers elsewhere, for example, on the ceiling, on the table, on the wall, etc. There is also another desktop computer which is used as the server and every tablet is connected to this server as a client.

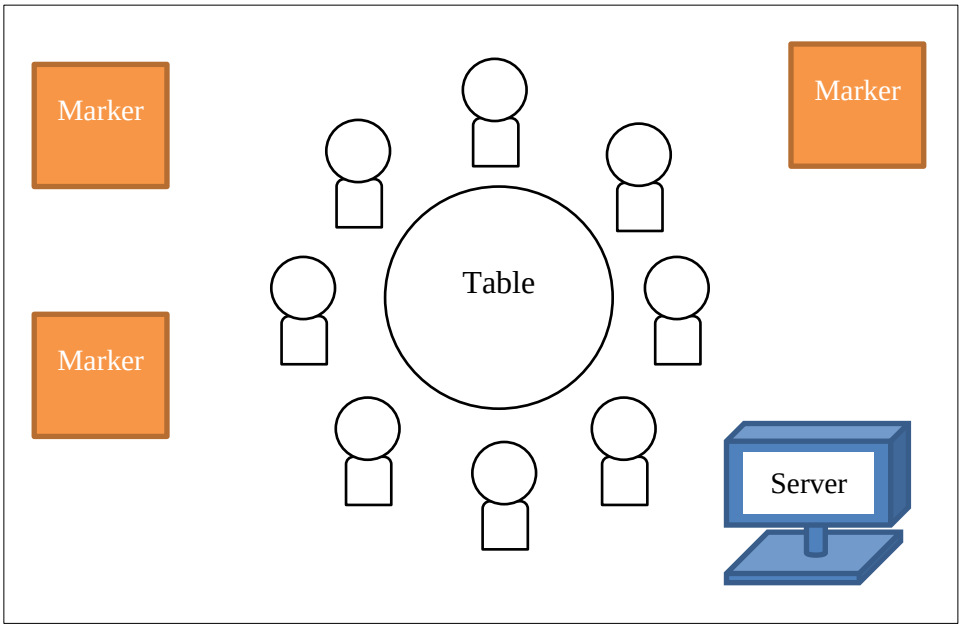


Figure 3-24 Holding a Bomb game - Initial game setting

On each turn, when the player receives a signal, he needs to find another marker to face at, either at the back of another player or somewhere else.

There are three ways to face another marker, upright, 90 degrees clockwise, and 90-degree counter clockwise.

If the pointed marker contains the bomb and faces the bomb upright, the bomb will be transferred to that tablet. If the bomb is not facing upright, the bomb will be revealed to that player but will not be transferred.

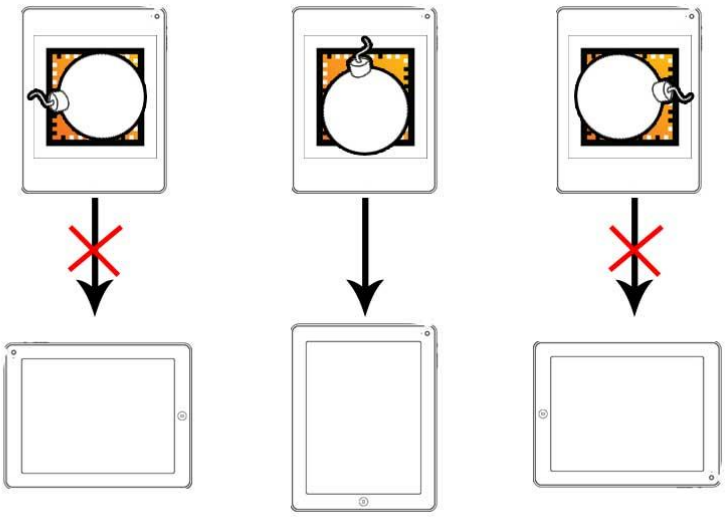


Figure 3-25 Holding a Bomb Game - Transferring the bomb

The bomb holding player is free to rotate his bomb to any orientations. Plus, he can place the bomb on the additional markers to trick the other players and he can retrieve it back. However, he is still considered holding the bomb.

The game will run faster every single turn. The player who cannot find another marker in time will lose his life. There are three lives for each player to lose and he will be immediately eliminated if he loses all his lives. When the time runs out, the player who holds the bomb will lose.

The game world

As this game is a multiplayer augmented reality game, the game will consist of two main parts of the game world, which are the physical world and the virtual world. In the physical world, the system contains a number of tablets for the players and a computer as the server. There are a number of markers to control the game flow. A number of markers will be attached to the back of each tablet

and the rest of markers will be securely attached to the other places in the playing room.

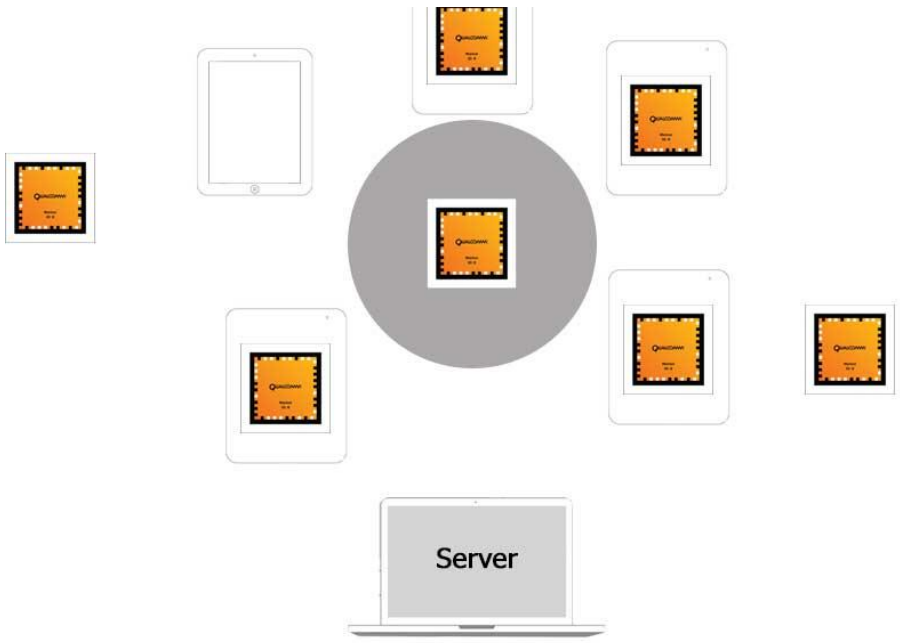


Figure 3-26 Holding a Bomb game - Physical game world

In the virtual world, the augmented objects are a bomb and the word 'Safe' according to what that marker is holding. The bomb orientations can be in three ways according to the player who holds it while the 'Safe' word will always be upright.

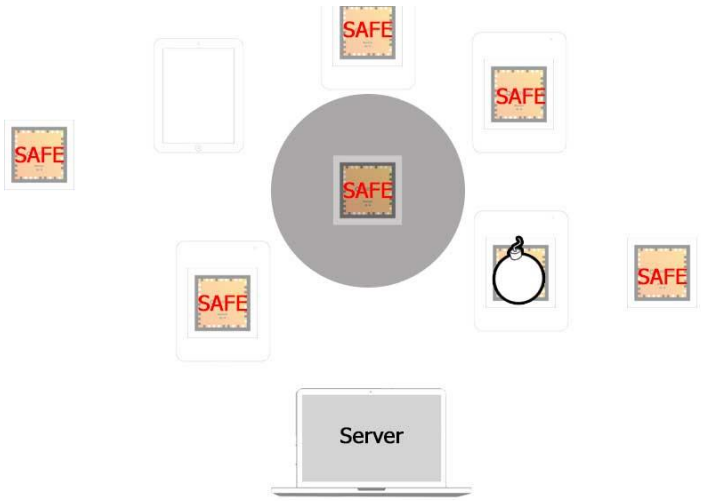


Figure 3-27 Holding a Bomb Game - Virtual game world

Game control

This game is controlled by each player's tablet. The player will use his tablet to point to another marker when there is a signal. The player can rotate the tablet in three orientations. If the tablet is facing the bomb upright, the bomb will be transferred.

Core augmented reality mechanism

The mechanism and the interaction between each marker at the back of tablet or public markers somewhere else are identical. When a signal is triggered from the server, each player needs to point his tablet to a marker in three different orientations. If a bomb is held on that marker and the orientation is upright, the bomb will be transferred to that tablet. All calculations will be held by the server. The augmented objects are the bomb in its orientation for the marker holding the bomb or a word "Safe" for the marker which is not holding the bomb.

Technical configuration

The game is set with a marker attached at the back of each tablet and a set of markers attached somewhere else in the playing room. There will also be a separate server and each tablet will be counted as a client and connected to the server. The activities that happen in the game will all be operated by the server. The information will be sent to the client.

Overall game operations will be server's responsibility, including the winning/losing conditions of the game.

Tower Defence Game

Game concept summary

This game is a simple version of the multiplayer tower defence games. The initial version of this game consists of three discrete lanes between two towers which represent the base of each side. The main objective of this game is to attack the opponent's base with whatever player has before his base is destroyed. The three lanes and two towers are augmented on a marker which is on top of a table.

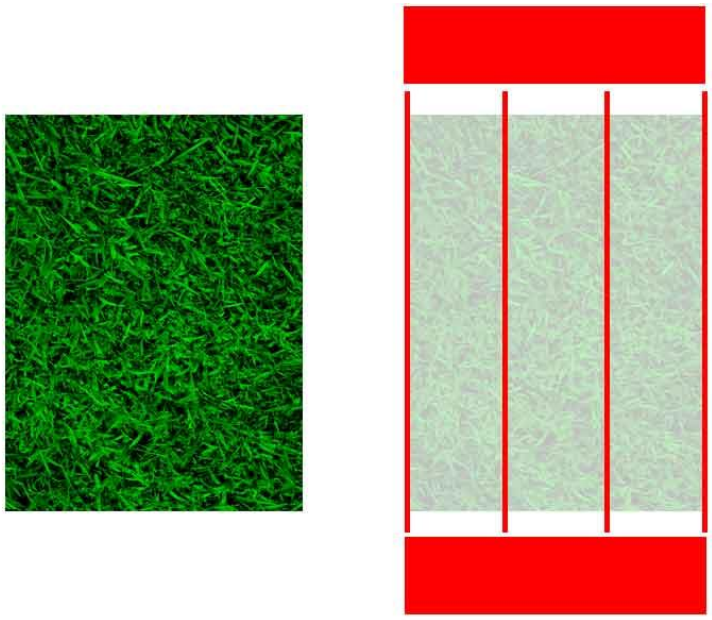


Figure 3-28 Tower Defence Game - The table-top marker and lanes/towers augmented on it

Each player can place a soldier on a lane using one of the three buttons on the screen representing each lane. If the soldiers from different sides meet each other in the same lane, they will start fighting until each soldier runs out of health points and is eliminated.

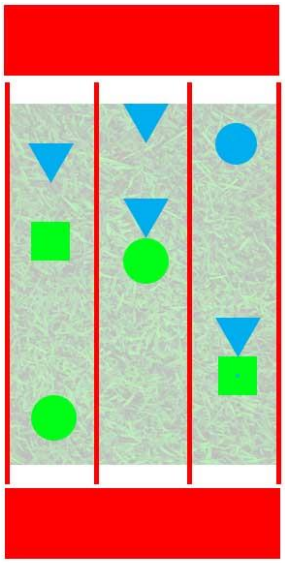


Figure 3-29 Tower Defence Game - Soldiers are clashing with each other

The soldiers who reach the opponent's tower will start attacking the tower until it runs out of health points and is destroyed. However, if a new enemy soldier is sent out on that lane, they will take priority to clash with each other before continuing to attack the tower.

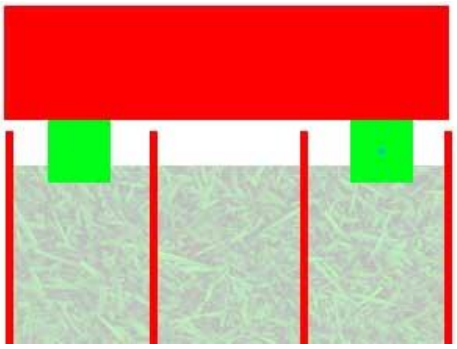


Figure 3-30 Tower Defence Game - Soldiers are attacking the tower

Furthermore, each player can fire one arrow every second by touching the screen. This arrow can be used to damage the opponent's soldier or damage the opponent directly. A player can be damaged directly by firing the arrow to the marker at the back of the tablet. The damage that the player receives will be carried to the tower.

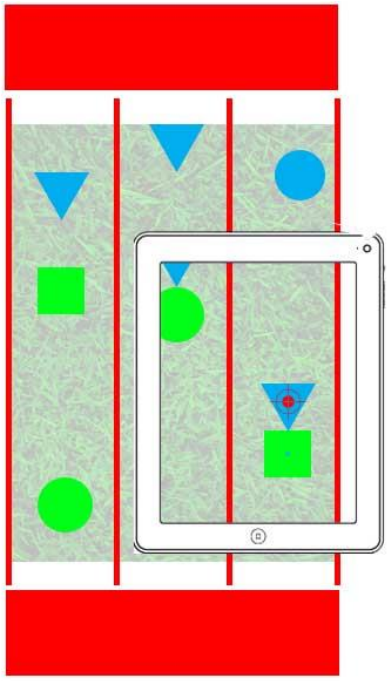


Figure 3-31 Tower Defence Game - Attacking with the arrows directly

The game will end whenever one of the towers is destroyed.

The game world

As this game is a multiplayer augmented reality game, the game will consist of two main parts of the game world, which are the physical world and the virtual world. In the physical world, the system contains two tablets for the players and a computer as the server. There are three markers to indicate each component of the game. One marker will be securely attached to the table to indicate the three virtual lanes and two virtual towers while the other two markers will be attached at the back of each tablet.

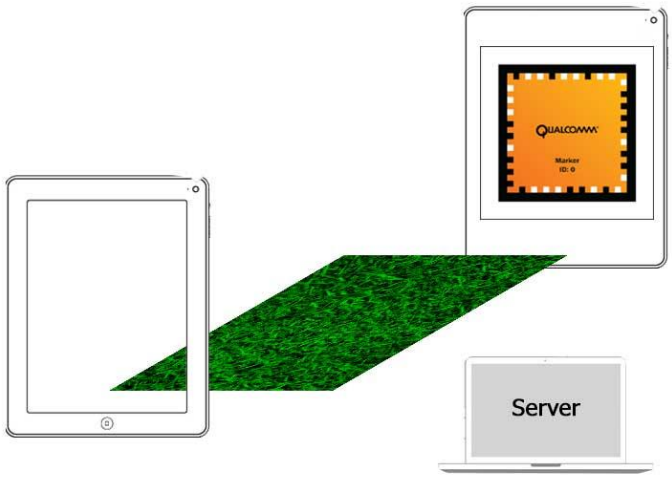


Figure 3-32 Tower Defence Game - Physical game world

In the virtual world, the main game components are augmented according to the physical markers. Three discrete lanes are augmented on the marker on the tables with two towers at each end. There will be three types of soldiers moving along each lane from their base tower to the opponent's tower. These soldiers are responsible for fighting each other to reach the opponent's tower and attack it.

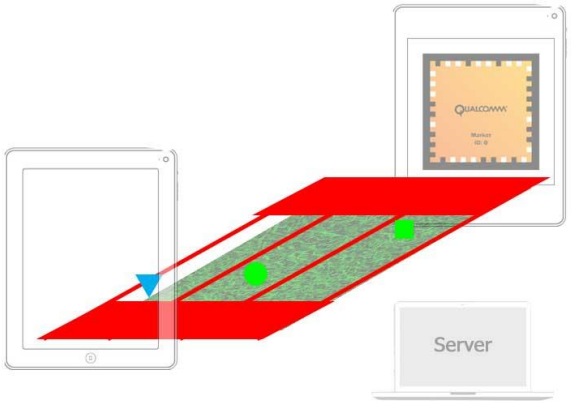


Figure 3-33 Tower Defence Game - Virtual game world

Game control

This game is controlled by each player's tablet. The player will use a touchscreen to place the soldiers on a lane and fire an arrow. The soldiers are placed using the buttons on the screen which represent each discrete lane while the arrows are aimed by the tablet's camera. The player should also be aware

not to expose his marker to the opponent's camera or he can also be attacked directly with the arrows.

Core augmented reality mechanism

As the system of this game consists of two types of markers – private ones attached to the back of the tablet and the public one on the table, the augmented reality mechanism and interaction between these markers will be as follows:

Tablet and table-top marker

There are two types of augmented reality between the tablet and the table-top marker. One is the operation on the tablet to put a soldier on the table-top marker. As the table-top marker represents the playable game area, apart from the virtual game world which is augmented on the marker, when the button to create a soldier is pressed on the tablet, a virtual soldier will be placed on the marker at the controller's side tower in the destined lane. This soldier will start moving and attacking automatically according to each situation. In other words, no other direct operation can be done to the player's soldier once they are put in the field. However, they can be viewed through each tablet if the tablet camera is pointed to the table-top marker. Their virtual objects and status will be conveyed to the tablet screen from the server according to an augmented reality view.

The other type of mechanism between the tablet and the table-top marker is a direct attack from the tablet to the opponent's soldiers. This can be executed by pointing the camera directly to the marker and touching the screen where there is no button. The arrow will be fired from the tablet to the marker. If the arrow hits the opponent's soldier, their health points will be decreased. The calculation whether an arrow hits a soldier or not is executed by the tablet which fires the arrow. A hit or miss result will be sent to the server, then the server will update the status and send all information back to both tablets.

Between two tablet markers

Only one action can be done between two tablets, which is a direct attack. When the marker, which is at the back of opponent's tablet, is visible and detectable, a virtual target will be shown on the screen. Thus, the player is able to attack the opponent directly. Similar to attacking a soldier, the hit or miss result is calculated by the tablet which fires the arrow and sends the information back to

the server. The server will update all status and send all information back to both tablets, which means the attacked tablet will be notified and able to hide his marker from his opponent.

Technical configuration

The game is set with one marker on the table and a marker attached at the back of each tablet. There will be also a separate server and each tablet will be counted as a client and connected to the server. Discrete lanes will be augmented using the marker on the table, as well as the soldier. The activities that happen on the table will be calculated and operated by the server. The information will be sent to the client whenever it detects the marker on the table.

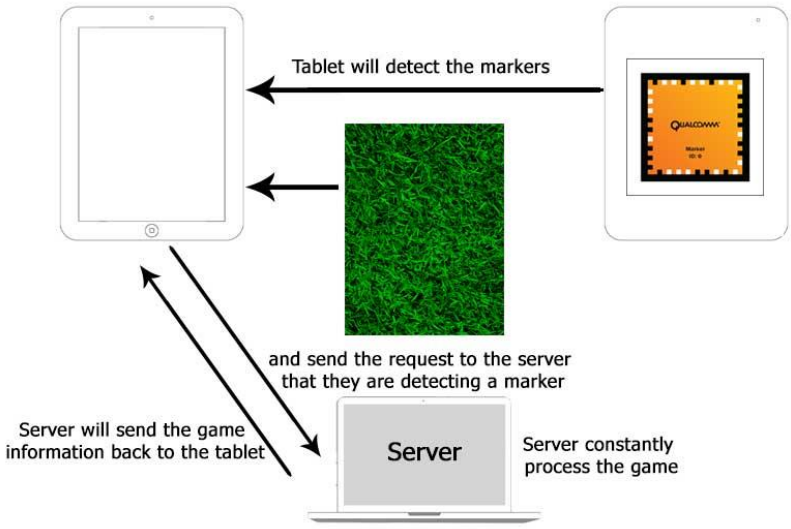


Figure 3-34 Tower Defence Game - Server / Clients operation (1)

Each player can attack the soldier directly by firing an arrow to the table. If the arrow hits a soldier, that soldier will be damaged. This activity will be operated by the client who fires the arrow and the information is sent to the server. Each player can also attack the other player directly. When a player detects the opponent's marker and fires an arrow, the firing client will send the information to the server to damage and notify the opponent.

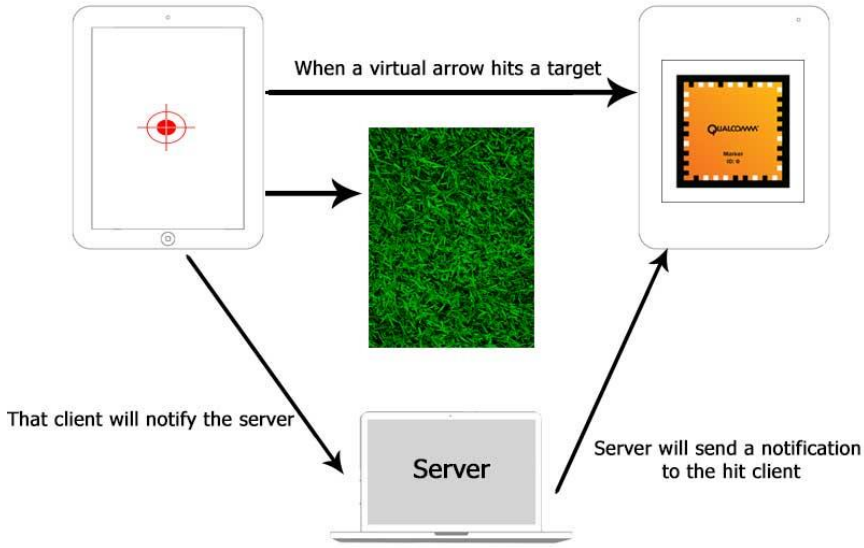


Figure 3-35 Tower Defence Game - Server / Clients operation (2)

Overall game operations will be the server's responsibility, including the winning/losing conditions of the game.

3.3.4 Designing workshop discussion and conclusion

To recapitulate, the purposes of this series of workshops were established into three points, which were well-served during the progress of the workshops. The first point was to construct a composition of the game design process which can help designers to design an augmented reality game, especially face-to-face augmented reality games, under the technology limitations. This point has been fulfilled since participants in this series of workshops can perform a game design well with a good reception in the interview at the end of each workshop. The process in these workshops still has rooms to further improve which could be discussed in future studies.

The second point was to produce an amount of example face-to-face augmented reality games. This is to serve the purpose of evaluating the outcome of the designing process in the workshops. Furthermore, these face-to-face augmented reality games can be developed further to be the games that are used in the studies later in this thesis. This point has also been fulfilled with three potential output games in Section 3.3.3.

The last point was to reveal any interesting or concerning issues in face-to-face augmented reality game design, development, or gameplay experience. During the courses of the designing process in the workshops, there were several issues

raised by the participants which are worthy to be explored more. The issues were pointed out into two distinct groups: additional technology feasibilities of face-to-face augmented reality games and innovative ways or settings of face-to-face augmented reality games.

In the workshops, the participants discussed and found some interesting additional technology feasibilities of augmented reality games that directly affected face-to-face augmented reality games and the research in this thesis. They found basic limitations such as response time and detection abilities of computer vision algorithms in augmented reality which can be a problem in game synchronisation. They also found more advanced limitations. One thing participants found was the perspective area of the camera is an important part of multiplayer augmented reality games. Since in a regular setting of augmented reality, there are only a few markers in the view of the camera. However, in multiplayer augmented reality games, it is possible that the game needs the camera to detect multiple markers at the same time where the perspective area might be too narrow. This depends hugely on the focal length of the camera. It can be a limitation or some interesting kinds of gameplay in which only two players agree to look and detect each other. This could also be an interesting social interaction group activity. Another point concerned a lack of network connection. This meant that, overall, the game could not recognise the state of each device. This might be a huge limitation for game designers as the states of each player are normally monitored by the game system in a regular game which could be a problem e.g. there is no way for the system to state the end of the game. However, this can also be used as a feature in special kinds of games such as a game in which some information is hidden from the players or a game that does not require each player to finish the game at the same time. The final interesting point that participants found was it is difficult to recognise the global position of each device as the positioning technology is not very precise.

On the other hand, the participants proposed simple settings of face-to-face augmented reality games such as in the game where one side of the players can be the only one that detects the opponent, or innovative settings such as in a face-to-face augmented reality game without verbal communication, a face-to-face augmented reality game in different rooms by using a camera to show each other which could be played at different times, an augmented reality game where a number of players can play and another group of players can spectate the game, an augmented reality game where a marker can be virtually concealed by another virtual objector different visions of players when markers are fully seen or partially concealed, or a multiplayer augmented reality game that is a hybrid between face-to-face augmented reality and table-top augmented reality.

In conclusion, the workshops were successful in serving their purposes and contributed to various points for the studies in this thesis and in the future. These

points will be used to establish the study areas of face-to-face augmented reality games in the next section.

3.4 Establishing study areas of face-to-face augmented reality games

Face-to-face augmented reality games have been observed, explained, and discussed in several aspects and levels through activities in the previous sections. These aimed to establish the study areas of face-to-face augmented reality games in the further part of this thesis. Augmented reality and face-to-face augmented reality are defined as a combination of the physical world, the virtual world, and a mixed reality world in between. Face-to-face augmented reality, its control, movements, and feasibilities are an attached relation between these three worlds in which anything that happens in one world can affect incredibly to other worlds.

The study in this thesis then will focus on how these happenings influence user experience and their deeds. These objectives will be observed in several aspects and levels. From each aspect of the physical world, the virtual world, and the mixed reality world. From a low level in which each player's actions and movements corresponding to face-to-face relative movements to a higher level in augmented reality game environment.

In a physical world aspect, as reviewed in Section 3.1 and 3.2, physical deeds and feasibilities are important in the face-to-face augmented reality game process. Therefore, it is interesting to observe how players perform the actions on their own and how they interact with each other to form a relative movement. These might be different in each type of game or setting of multiplayer relationships. These actions and interactions should also alter overall game experience in which it is also observed. On the other hand, in the virtual world, the study will focus on observing how an augmented reality gameplay, which is designed for face-to-face interactions, puts an impact on the player experience, actions, and decisions. The observation should also be included if there is anything different from a typical augmented reality game.

In a mixed reality world aspect, which includes all augmented reality processes, as it is an overlapped area of the physical world and the virtual world, each part of them will be studied on how they influence players, for example, the marker detections, marker design, object overlaid, etc. These areas of study will continue in the next few chapters.

3.5 Conclusion

In this chapter, face-to-face augmented reality games were explored thoroughly to serve the purpose of establishing the area of study in further chapters. It started with expanding the Reality-Virtuality Continuum in Chapter 2 with each event in face-to-face augmented reality games. This revealed that events occur relatively in each world and cannot be considered separately. A series of initial observations and trials were put on the translations of six degrees of freedom movements and a few metaphors. These showed an initial feeling and thought of face-to-face augmented reality games as well as revealed their limitations.

Feasibilities of face-to-face augmented reality games then were explored. Various aspects of feasibilities were reviewed including ergonomics of face-to-face interactions, technology and hardware used in face-to-face interactions and gameplay, and the augmented reality limitations. Within these boundaries which are difficult to alter, the question arising is how a face-to-face augmented reality game will be designed.

A few workshops of face-to-face augmented reality game design then were conducted. The workshops had three purposes which were to construct a composition of a game design process which can help designers to design a face-to-face augmented reality game under the technology limitations, to build face-to-face augmented reality games which could be examples for the future references, and to reveal any interesting or concerning issues in face-to-face augmented reality game design, development, or gameplay experience. The workshops were successful, and all purposes were satisfied.

In the end, areas of face-to-face augmented reality game study were established using the information in this and the previous chapters. These areas of study will be carried over to Chapter 4 and the further chapters which is the main point of this thesis.

Chapter 4

A study of face-to-face augmented reality games

Face-to-face augmented reality games have been explored in Chapter 3. Their feasibilities and possibilities have been unfolded and the areas of study involving aspects of face-to-face augmented reality games in the physical and virtual worlds have been established. In this chapter, these areas will be studied by using a multiplayer augmented reality game, with integrated face-to-face movements and interactive features as the spine of the study. Firstly, the concepts and objectives of this study will be described. After that, the design of this study, which is based on observations on actual users' gaming experience, will be presented and the results of the study will be revealed. The chapter will finish with a discussion on the results to establish the further direction of the research. It is expected that, by the end of this chapter, the observations on established areas of study will be shown and any hidden issues in the face-to-face augmented reality game area will be exposed.

4.1 Study concepts and objectives

The study of face-to-face augmented reality games in this chapter emerges from the exploration of the topic in Chapter 3. In the last chapter, many issues in face-to-face augmented reality games surfaced with observations on actual gameplay, for example, when metaphors of face-to-face augmented reality were developed and observed to discover limitations of the setting, or when using a designing workshop to explore the possibilities of the technology. Therefore, face-to-face augmented reality games should be able to be studied from the actual gameplay observation as well.

In this study, an augmented reality game, which highlights face-to-face interactions as the main feature, is going to be developed. This game is derived from materials and information received from the designing workshop in the previous chapter. The game will be observed in aspects mentioned in Chapter 3 including how players perform face-to-face actions and how they interact with each other to perform relative movements, how social scenarios and relationships in a game influence those actions and interactions, how these impact the gaming experience, how augmented reality technology affects these back and forth as well as the other components in a game, and how limitations of the technology involves the player's actions and decisions as well as their experience. The results from these observations will be discussed to set the next approach to the study.

From the core-mechanic point of view of a face-to-face augmented reality system, the players' movements and their limitations directly affect each player's experience. The study objective, which will be explored in this study to unfold the best practice for face-to-face augmented reality experiences, lies in these two parts.

Difficulties in performing each movement

To perform a face-to-face augmented reality movement, the player performs a device movement in six degrees of freedom as presented in the previous chapter. However, in the real world of three dimensional spaces, each movement has a different difficulty to be performed due to body movements, ergonomics, etc. An intention to perform one gesture can eventually be interpreted into another gesture. Furthermore, different difficulties of sets of movements could affect the whole game experience. In addition, the gameplay settings and social scenarios could also alter the difficulties of movements. Therefore, an observation on these movements is a fundamental question for face-to-face augmented reality and it is expected to implement the guideline for designing movements into an augmented reality system.

Limitations of movements

As mentioned above, each movement could contain limitations. In addition to the theoretical limitations listed above which occur from the limitations of the marker detection, there could be other limitations from the physical movements, gameplay settings, and social scenarios. These limitations are unforeseen unless an actual gameplay is performed. Therefore, this is

another fundamental question for face-to-face augmented reality and it could put the restraint guideline for future augmented reality designers.

In this study, these two points will be mainly observed in different social scenarios. User behaviours should change according to the scenario and unforeseen user experiences and behaviours are expected to emerge as much as possible.

4.2 Study design

In this section, the game being used in the study and the study layout will be presented. The format of this study was settled after a few pilot studies were tested, improved, and iterated a couple of times. These pilot studies also provide interesting results which will be included in the study results section later.

4.2.1 Design of studied face-to-face augmented reality game

The face-to-face augmented reality game study in this research is conducted by observing user experiences and behaviours while users are playing a face-to-face multiplayer augmented reality game. Therefore, in this section, the game concept and development process will be explained. The game is designed based on advantages of three output games from a series of design workshops in Chapter 3. To recapitulate, there are three games produced as a result of the workshops, which are Red Army Factory, Holding a Bomb, and Tower Defence. These three games are different as the selected designing cards in the workshops were picked randomly and they hold different advantages for face-to-face multiplayer augmented reality games. These advantages are explained below.

Red Army Factory

This game contains several components which benefit a face-to-face augmented reality games study. Firstly, the setting of this game contains markers at several places apart from at the back of the devices. This is an interesting setting of augmented reality games. Since the markers are in different places across the game playing space and they represent different entities in the game, it is expected that the players will move around. This brings many interactions with other players and markers. Furthermore, because of this setting, it is comfortable to observe the interactions between the players and the markers compared to the interactions between two

players. This should be one of the main observations of face-to-face augmented reality games.

Secondly, the main game mechanics of this game is to order the players to perform movements with the marker per the server's signal. Performing a movement with the marker could lead to a relative movement between the players since there are some markers attached to the back of the devices. The benefits of observing face-to-face actions and their limitations would be the fundamental element for face-to-face augmented reality games.

Thirdly, the main objective of this game is that the players need to work cooperatively to process the whole game smoothly. It is interesting to observe the whole process of the game when the players work together to overcome any obstacles that might occur, especially when playing an augmented reality game with several limitations.

Holding a Bomb

This game is set with a similar setting to the Red Army Factory game. There are markers in several places and some of them are attached to the back of each player's device. There is one benefit from this game for a face-to-face augmented reality study. Since the game objective is to ask the players to conceal their current situation, it is interesting to observe how this affects the whole game experience because one of the possible occurrences in face-to-face multiplayer augmented reality is that a player will not acknowledge the current situation of the other players unless the screen is shown. However, it is obvious that the players can choose to conceal their screen which also conceals their situations. This could be implemented as one of the game goals in face-to-face multiplayer augmented reality games in the future.

Tower Defence

There are two advantages in this game. Firstly, this game contains two parts – the table-top marker which possesses the main game board and the tablet marker which represents the player's identity. It is an interesting component because this setting is like typical augmented reality games with some movable markers enhancement. This could benefit a study of face-to-face augmented reality games by observing this enhancement experience compared to the typical augmented reality setting.

Secondly, as the main game is running on the main table-top marker, it is interesting for a game which contains different attention points. Players

must balance between processes with minor objectives that could improve their situation and maintain the main objective on the game board. This could be interesting for face-to-face augmented reality games which give players different tasks with one major task and to observe how they process the gameplay.

Development of game design

The first attempt on the game design which possesses advantages of all output games from the workshop series is an adaptation of the Tower Defence game. The game is designed to observe face-to-face interactions between the players and the static marker compared to the interactions between two players one of which possesses a movable marker. This is expected to study their user experiences and limitations as well as any unforeseen circumstances. Furthermore, this game is expected to observe face-to-face multiplayer behaviours, which means this game's flexibility should be expanded on several multiplayer levels.

The adaptation of the Tower Defence game is designed to remove any wireless communications between devices to focus on the player's activities on performing face-to-face interactions. The game inherits the main part of the main virtual game board which is overlaid on the main table-top marker. However, the difference is that instead of having two sides of players competing, which is impossible if the wireless communications are removed, only one side competes with the system. Furthermore, to enable multiplayer gameplay, there will be another player on the same side as the first player. Since there is no wireless connection, the second player cannot acknowledge the first player's situation on the main game board. This is one of the challenging game design problems. To solve this problem, the supporter role is appointed to the second player instead of a player role. The supporter does not know the situation of the player unless they inform each other. However, it is also not important for the supporter to know the situation on the game board. A different task is given to the supporter to be completed individually and this task should also benefit the main player.

From all the requirements, an enhancement of the Tower Defence game has been designed. There are two roles in this game. The main player role is directly inherited from the first Tower Defence game design. The player must defend the main tower from the system's soldiers by placing his own soldiers to fight them and attack the opponent's tower to win the game. The enhancement part of this game is that the player's soldiers are given by the supporter. The supporter must perform a series of movements to interact with a marker called 'Spawn Point' to retrieve a soldier and pass it to the player using another series

of movements which imply face-to-face interactions. The player then puts this soldier to defend his tower. The player cannot interact with the spawn point. Meanwhile, the supporter cannot interact with the game board. This requires a lot of cooperative works and communications to process the game. Both players are appointed a distinct task, but they can support each other and win the game together. The flow of this game is shown in Figure 4-1.

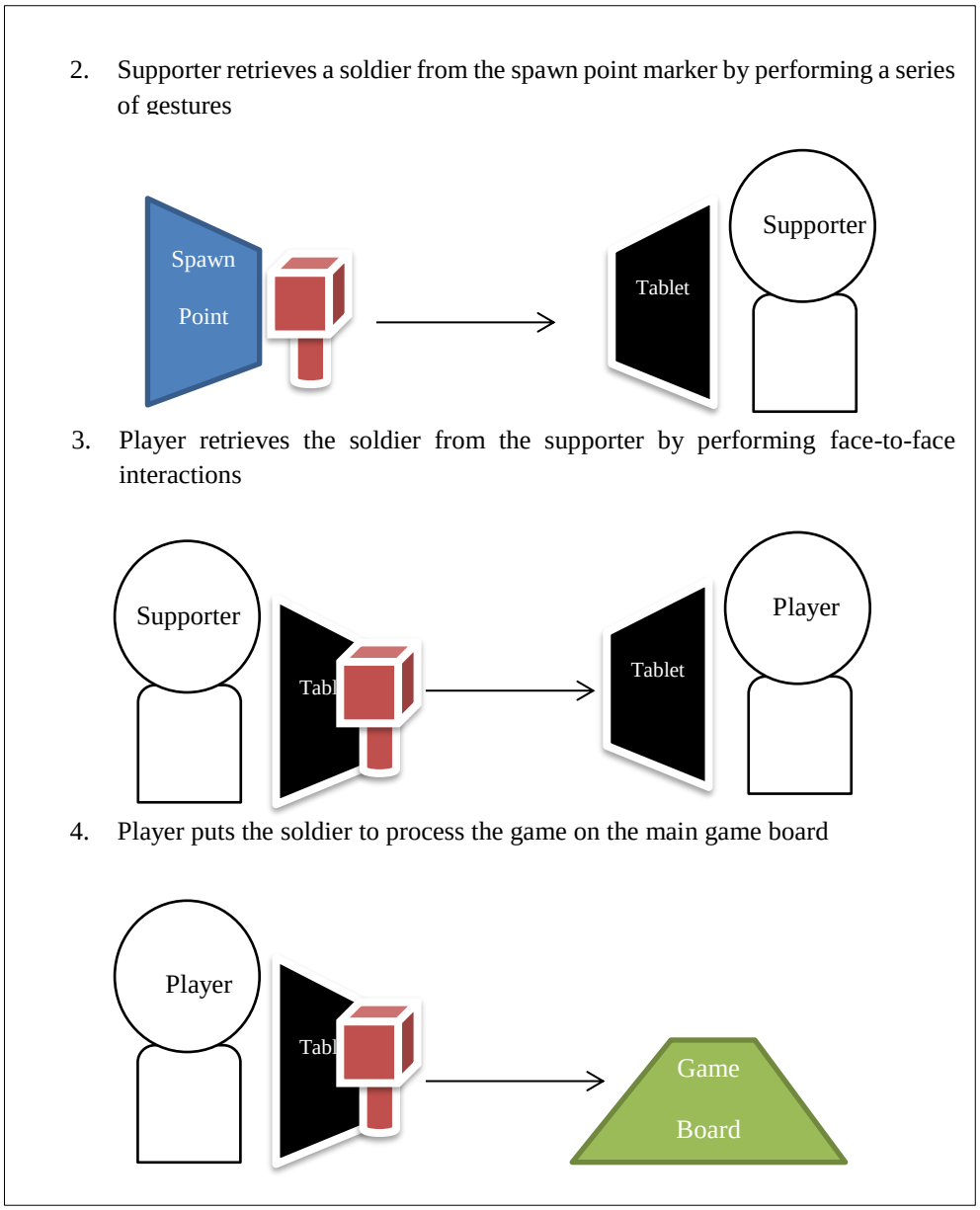


Figure 4-1 Setting of the adaptation version of the Tower Defence game

After a few play tests, there are some considerations on the advantages and disadvantages of this game.

Advantages

This game has set a game mechanics which hugely features performing movements and face-to-face interactions. There are two distinct roles and both roles have a different set of markers which can be interacted with. The mechanics carrying an object from one player to the other player is interesting and this enables a game which does not contain any wireless communications between devices. This is good for a face-to-face augmented reality game study.

Disadvantages

There is one big flaw in this game mechanic. Since there is no wireless connection, it is impossible for both players to know the current state of the other. It means that it is impossible for the supporter role to know if the player successfully retrieves the soldier, which means the system cannot determine if it should show the soldier on the supporter screen. On the other hand, the player does not know if the supporter manages to retrieve the soldier before interacting with the player. This affects hugely on the user experience. Furthermore, this game does not hold feasibilities for a competitive game setting while a multiplayer games study should be in both cooperative and competitive to observe the difference of user experiences and behaviours.

Considering advantages and disadvantages of this game, a different approach of game design has been introduced. It has adopted the advantages of this game and relieved its disadvantages. This is the final version of game design

Final game design

This game adopts the concept of non-wireless connection multiplayer games. The concept of sending and retrieving virtual items using face-to-face interactions and a distinct set of markers that can be interacted only by a certain player are also inherited in this game. However, the most challenging problem from the previous game design is how the players process the game and support each other without knowing the other player's situation.

A game called 'Johann Sebastian Joust' (Wilson, 2011) was introduced during a series of game design workshops in Chapter 3. This game is a great example of multiplayer games without wireless connections. Each player knows only the current self-situation. They process their game with the tasks given and the other

player's actions directly affect the game situation. This is interesting for designing a multiplayer game. The task concept is given to each player. Their tasks are similar to that of each other and their actions affect the other player's situations. This is adapted to the final game design.

The game context is set in a laboratory where the players will be given tasks to deliver as many chemical solutions as possible within 5 minutes. There are two types of markers for each player's tasks, which are the marker where the player receives the orders 'workstation' and the marker where the player performs a series of gestures to retrieve chemical solutions 'spawn point'. Markers are designed to be easy to understand and appropriate to the game context which is a laboratory area. Since there are two to three players for the initial version of this game, each player is represented by colours – red, yellow, and blue. The markers for each colour are presented in Figure 4-2.



Figure 4-2 Workstation markers (Top) and spawn point markers (Bottom)

Additionally, there is another type of markers attached to the back of each player's device 'processor' representing the place where the chemical solution will be processed with another substance. The marker of each colour is presented in Figure 4-3.



Figure 4-3 Processor markers

The game is initially set as in Figure 4-4.

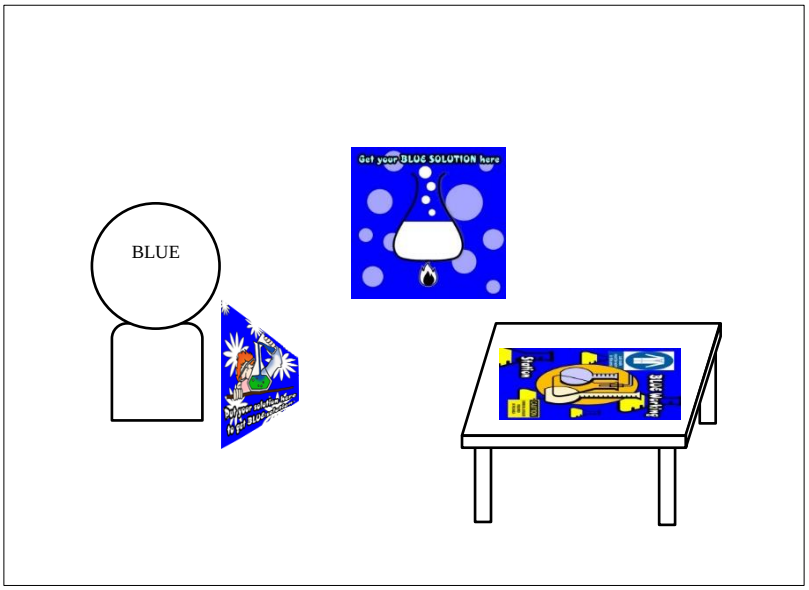


Figure 4-4 Game initial setting for one player

The game flow starts with the player detecting the workstation marker to receive an order. The list of orders will be given to the player at the centre of the screen when the workstation marker is detected as shown in Figure 4-5.

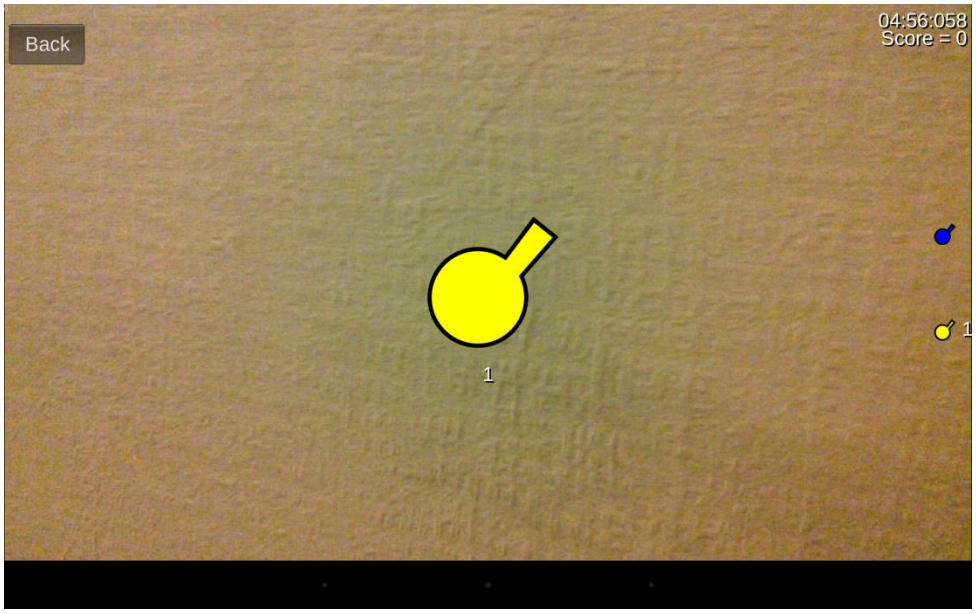


Figure 4-5 Orders given to player

After that, the player is required to find the spawn point marker to retrieve the chemical solution. The spawn point marker is augmented with a virtual flask and the player must perform a series of gestures to retrieve it as shown in Figure 4-6.

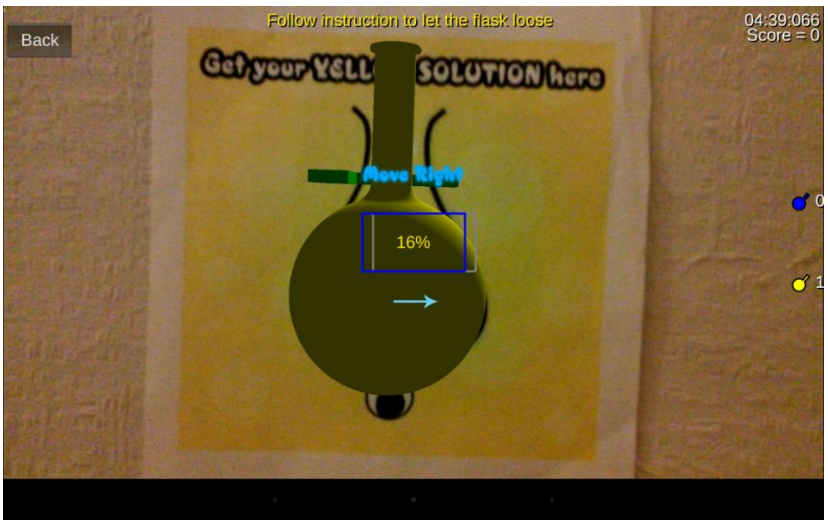


Figure 4-6 Movements are required to perform in order to retrieve the chemical solution

Once the series of gestures are successfully performed, the flask will be attached to the player's device instead of a marker to indicate that the gestures are successful, and the chemical solution is ready to be delivered.



Figure 4-7 Chemical solution is ready to be delivered

There are also orders to retrieve the chemical solution in different colours. To retrieve these solutions, the player must retrieve the flask from his spawn point first. The player then must find the other player to perform a series of gestures which represent the chemical process. Once the gestures are successful, the colour of the chemical solution will change to the colour that the player has processed with.

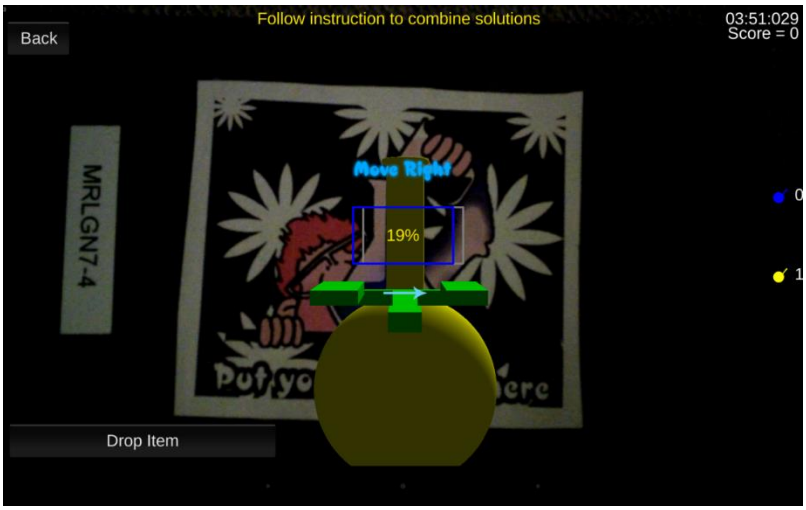


Figure 4-8 Process on chemical solution with processor marker

The player must deliver the solution back to the workstation and perform the final gesture that imitates a ‘pouring’ gesture to put the solution on the workstation tray. However, if the colour put on the workstation is not in the list of orders, there will be an explosion effect to indicate that the solution is not

needed. After the solution is successfully delivered, the cycle will be repeated until the time is up.



Figure 4-9 Chemical solution is poured to the workstation

This concludes the design of face-to-face augmented reality game that is used in the study.

4.2.2 Study layout

The study layout should be designed to provide a good learning curve and a good 'experience' to study participants to improve the effectiveness of the data. Therefore, from the initial study layout, gameplay had been tested several times. After a few pilot studies, the study layout has been finalised.

Firstly, participants are asked to perform training in a training session to familiarise with the movements in the game. After that, there are three major social scenarios in the study, which are single player, cooperative, and competitive, to differ their relationships which could affect the user experience. Participants are asked to play a face-to-face augmented reality game and their actions, reactions, decisions, and behaviours are recorded. After that, they are interviewed and are asked to share their experience which contributes to the data of proposed questions.

From above, there are four main sessions in this study – Introduction and Training, Single Player, Multiplayer - Cooperative, and Multiplayer - Competitive. These sessions will be explained in detail.

Introduction and training session

This session is designed to plant a good mutual understanding of face-to-face augmented reality to participants. Some examples of augmented reality systems are presented, and the research objectives are introduced. Participants also have an opportunity to try to perform movements with a proxy marker until they are confident with the movements before moving on to further sessions.

The marker used in this session is a default marker of the Vuforia engine, in Figure 4-10, to simplify the development as it is one of the best detectable marker.



Figure 4-10 Marker in training session

The screen of the system used in this training session is simplified. There is only a primitive cube object augmented to the marker to indicate that the marker is detected. However, there are a couple of issues to be tested in this session before advancing to the single player session. These issues focus only on the questions that should be observed by not being interfered with gameplay.

Firstly, participants are asked to test two different kinds of user interfaces for movement guidance. In the training, the next movements that the player needs to perform are put as a user interface at the middle of screen. However, in this test, there is another user interface which the current situation of the device and the target for movements are added. After trying a series of movements using both kinds of user interfaces, they are asked to give a score of difficulty of those user interfaces from zero to ten where zero is the hardest to perform and ten is the easiest to perform. This is expected to

observe how gameplay affects player's movements and how augmented objects affect user experience. By adding the guidance and target of movements, it is expected that it would be easier for the player to perform those movements than the user interface without an assistant. The concept of these two kinds of user interfaces are shown in Figure 4-11.

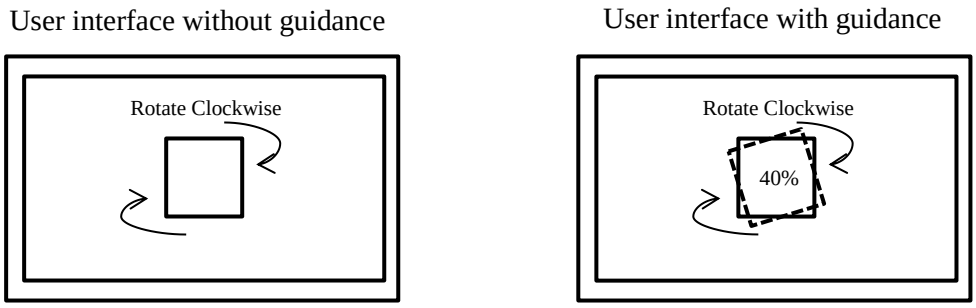


Figure 4-11 Concept of two kinds of user interfaces

The screenshot of the user interface without guidance version is presented in Figure 4-12.



Figure 4-12 Training session interface – without guidance version

The user interface with a guidance version is put together with the current orientation of the device and the target of the movement, as well as the percentage of completion when the movement is performed. The screenshot of this user interface with a guidance version is presented in Figure 4-13.

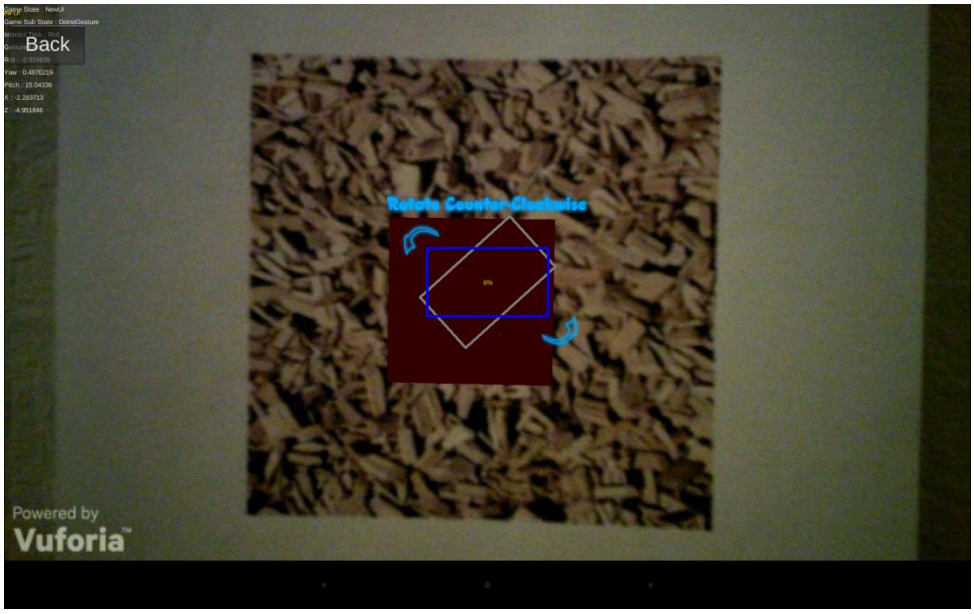


Figure 4-13 Training session interface – with guidance version

Secondly, participants are asked to perform each individual movement and put those movements to the last point where they feel comfortable to perform. This is to test the critical point of each movement which is expected to answer the question of what the physical limitations of each movement are.

After they finish the training session, they will move to the actual game part with a single player mode.

Single player session

This session is the first session of the actual gameplay. Participants are asked to play a game which requires performing a series of movements with the marker and scoring as much as they can within a time limit. Gameplay which is used in this session requires only performing movements with the markers in the player's possession. This expects to set the baseline of understanding of movement performance before any other gameplay or social scenario influences on the player's movements.

After the time limit, participants are asked to give their opinion on two topics. Firstly, they are asked to think about the whole experience from the gameplay and rate the understandability of this game from zero to ten where zero is the hardest to understand and ten is the easiest to understand. This is expected to understand how the whole gameplay affects player experience and how comfortable they are with a typical augmented reality system. The

gameplay in this session is like regular augmented reality systems apart from the fact that the players are not moving.

Secondly, participants are asked to share their opinion on each movement they performed during gameplay and rate the gestures from zero to ten where zero is the hardest to perform and ten is the easiest to perform. The movements in the gameplay are put together with basic movements in six degrees of freedom which are translated left and right, up and down, in and out, roll rotations, pitch rotations, and yaw rotations. This is to set the baseline of their opinion on the gesture difficulty before being affected by the gameplay and to study the difficulty in performing each movement to understand the movements from the user experience point of view.

Multiplayer - cooperative session

After the single player finishes, the study continues to a multiplayer session with a cooperative setting. It is expected to have two or three players playing in this session. The number of players would also affect the experience of gameplay. Participants are asked to play the same game as the single player session with multiplayer features and they are asked to cooperate with each other to deliver the highest total scores as possible. The multiplayer version of the game does not contain any sharing information among devices such as using a wireless connection. Therefore, each player only knows his situation and must rely on physical communications to pass the message. This is also to reduce the complexity of gameplay which could affect the gesture performance. They will be encouraged to talk with each other and work to deliver the best results together.

In this session, many circumstances are expected to be revealed in terms of a cooperative scenario. As before, participants are asked to give their opinion about their experience after playing the game twice. Firstly, they are asked to give their opinion about how they find their experience compared to the single player version to retrieve the data of user experience of a multiplayer play setting.

Secondly, participants are asked to share their opinion on each movement they performed during gameplay and rate the movements from zero to ten where zero is the hardest to perform and ten is the easiest to perform, the same way as the single player session. As it is anticipated that the social scenario would affect the movements, it is interesting to discover if the movements are easy to perform.

Thirdly, participants are asked to share their opinion on how communications play a role in a multiplayer game, especially a face-to-face

augmented reality game where mutual understanding of the game is important. This is to understand how the physical interactions and communications affect the gameplay experience.

Multiplayer - competitive session

After the cooperative session, the study continues to a multiplayer session with a competitive setting. As in a cooperative session, it is expected to have two or three players playing in this session and the number of players would also affect the experience of gameplay. Participants are asked to play the same game, but they are asked to compete to deliver the highest individual scores instead. They will be encouraged to talk with each other to allow them to plan any tactics or psychological strategies to enhance their situation. The playing in this session is to fulfil the face-to-face multiplayer augmented reality experience from a different social scenario.

Participants are asked to give their opinion about their experience after playing the game twice. Firstly, they are asked to give their opinion about how they find their experience compared to the cooperative version to retrieve the data of user experience of a multiplayer play setting.

Secondly, participants are asked about their opinion on each movement they perform during gameplay and rate the movements from zero to ten where zero is the hardest to perform and ten is the easiest to perform, the same way as the sessions before.

Thirdly, participants are asked to share their opinion on how communications play a role in planning their tactics. This is to understand how the physical interactions and communications affect the gameplay experience.

Conclusion session

After all sessions are played, participants are asked to give their final opinion. They are asked about all three social scenarios and rate the degrees of enjoyment on each scenario from zero to ten where zero is the least enjoyment and ten is the most enjoyment. They are also asked to share any experience they find interesting while playing in each session. After that, they are asked about their final thoughts of this game mechanics and how this mechanics could be improved to a kind of game. In addition, they are asked about their idea on face-to-face multiplayer augmented reality games. That concludes this study.

4.2.3 Other important study components

These are the other important components for the study.

Study venue

An indoor room with a suitable lighting condition for an augmented reality system.

Expected participants

To maximise the study data, participants should be anyone who has any of these attributes: -

- Interested in augmented reality
- Have related computer field backgrounds
- Related to computer games development
- Often play games

Number of participants

Two or three participants per study to reduce the complexity of social scenarios.

4.3 Study results

The study has been successfully designed and a face-to-face augmented reality game has been developed. A series of studies have been conducted to observe the player's behaviours and decisions as well as their experience as the study's objectives proposed in Section 4.1. In this section, those observations and the interviews will be presented in detail before they are concluded and discussed in the next section. To begin with, some basic information of the studies will be explained below.

Basic information of the study

These series of studies have been conducted six times, two times as pilot studies and four times as actual studies. However, all six studies will be presented together because the structures are similar and the observations on pilot study also provide some thought-provoking issues.

There are two or three participants in each study. Participants are both male or female who are between 23 to 60 years old. All participants have either background in either computer science or games. However, not every participant has experience in augmented reality technology before. Some

participants might have heard about the technology but have never tried it while some participants have never heard about the technology.

There are three types of devices used in this study, which are Acer Iconia 501s running on Android 3.2, Galaxy Note 10.1 running on Android 4.4, and Google Nexus 7s (2013) running on Android 5.1. However, devices are identical in each study, as well as the installed system.

The studies were conducted in a room with suitable lighting to avoid having troubles on image detections during the studies.

The results will be presented below in each session of the study.

4.3.1 Introduction and training session

All participants were introduced to augmented reality in advertisements and games. Some participants were not familiar with the technology. Therefore, a few images and videos of the technology were shown to those participants to provide a basic idea of the technology to them. They were then introduced to multiplayer marker-based augmented reality and the concept of this research about multiplayer, face-to-face setting, physical communications, and physical movements and interactions.

Participants were then introduced to the training session of the game. The training session gave an opportunity for each participant to try performing augmented reality physical movements until they were satisfied. After that, they were given a task to perform a series of movements twice, the first time without guidance and the second time with guidance. Finally, all participants were asked to share their opinions during the training session.

Initially, participants struggled with how the physical augmented reality movements worked. However, they eventually familiarised themselves with the system after some explanation. Then the following questions were asked.

1. **How did you feel about physical augmented reality movements?**
   Most of the participants commented that they felt that the performance of the movements was realistic, especially compared to playing regular computer games. However, they struggled at first since they had no experiences in physical movements. They felt that there was a great difference between performing movements and playing regular games on a touch screen since it was not required to touch anything, and it was confusing for them. They also struggled with how much they needed to move at the beginning and how sensitive the detection was. Nonetheless, they eventually familiarised themselves with the movements and they thought that it was easy to understand and to learn the nature of the

system and movements. One participant commented that he felt strange because although he was playing a game in a big room, he needed to focus on a tiny screen which was contradictory for him.

2. **Which kinds of movements were difficult and which ones were easy?**
   Participants were asked to rate the scores from zero to ten as the difficulties of the movements to put their opinion on each movement in order.

   Moving in and out:

   Most of the participants found that moving in and out was the easiest set of movements they performed. However, one participant disagreed. Like other participants, he found that moving in was the easiest movement. However, he thought that moving out for him was moderately difficult. He commented that moving out caused him to move the whole body and sometimes caused a detection loss from that movement.

   Moving left, right, up, and down:

   Most of the participants also found that these movements were the easiest set of movements, on par with moving in and out. However, one participant found that he was confused between these movements and tilting movements. However, once he understood he felt more comfortable to perform the movements, but he felt they were still slightly more difficult than moving in and out.

   Rotating and Tilting:

   The opinions about these movements were split in half. One group found that rotating was more difficult than tilting and that it was the most difficult set of movements. They found that it was challenging to hold the device still and not to lose the detection while performing a rotation. Furthermore, when they rotated, they often obstructed the screen and the camera with their hands and fingers. Lastly, when they tried to perform the rotation, the camera focuses always swayed from the marker. The other group of participants disagreed. They found that tilting was much more difficult than rotating and that it was the most difficult set of movements. They commented that the movement easily caused a detection loss and it was difficult to move. Nonetheless, all participants found that these movements were, by far, more difficult than moving in, out, left, right, up, and down.

3. **What is the difference between two types of interfaces in terms of movements, with guidance and without guidance?**
   All participants found that the interface without guidance confused them on how much they should move and how they should perform the

movements. They all preferred the interface with guidance. They commented that it was much easier to perform.

After that, the studies proceeded to the single player session.

4.3.2 Single player session

After participants had had a full understanding of the game flow and felt confident enough to perform in an actual session, the study proceeded to a single player session where they did not require interacting with the other players. After an initial observation, it seemed that participants could be divided into two major types. The first was those who rushed to markers and moved their device rapidly because they were asked to do their best and compete with the other players to achieve the highest scores. This led to a lot of detection loss due to either a hasty move or lighting conditions although most of them performed well during the training session. Eventually, most of the participants in this group slowed their movements down and they could perform the tasks better.

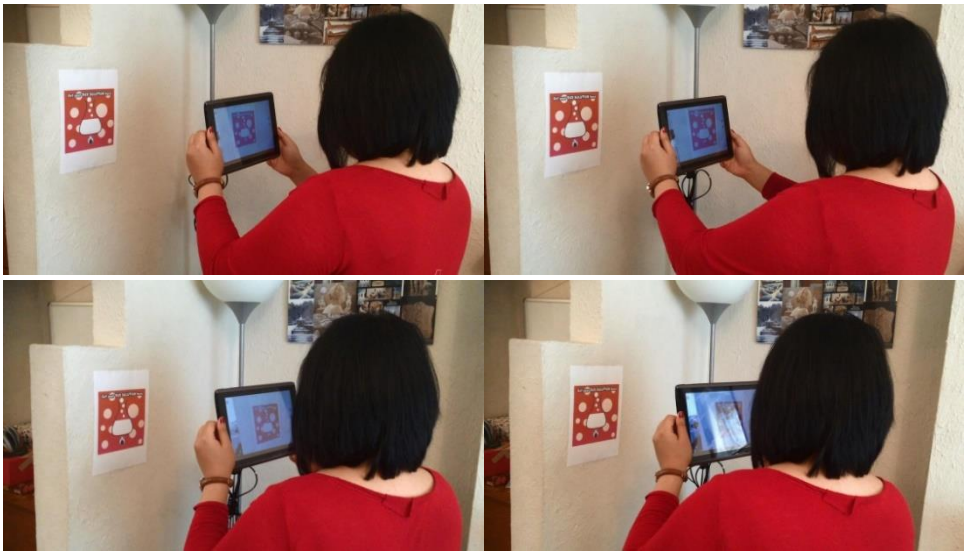


Figure 4-14 A participant tries to detect the marker and eventually slows her pace.

On the other hand, the other group of participants carefully and slowly performed the movements. Their movements were slow at the beginning, but they eventually improved their speed over time. They did not suffer from the detection loss as much as the first group.

It was also noticed that some participants were still uncomfortable with only performing movements in an augmented reality system. Some participants still unconsciously touched the screen when they lost the detection, as shown in Figure 4-15.



Figure 4-15 A participant unconsciously touches the screen to solve the detection problem.

It is worthwhile to note that most of the players held the device in two different ways. Some players held the devices with both hands, grabbing the device from the front while the others held their devices from the sides, as shown in Figure 4-16.

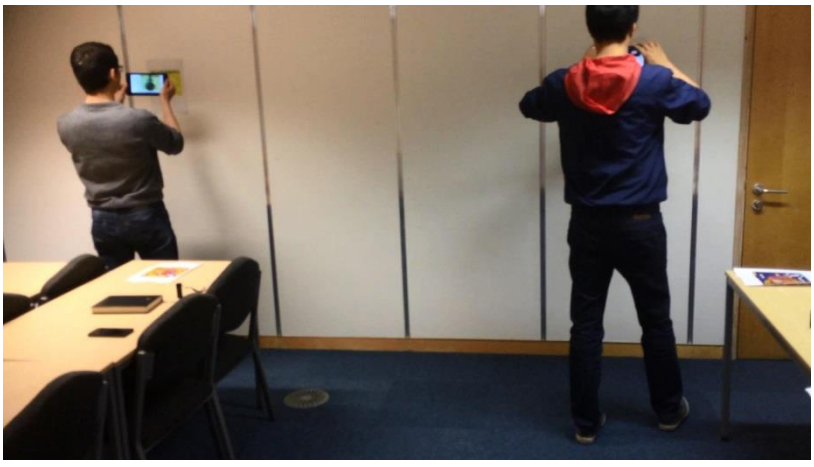


Figure 4-16 Participant on the right grabs the device from the front while participant on the left holds from the sides

It seemed that the way each participant held the device also moderately affected on their marker detection. Participants who held the devices from the sides often lost detection. It was because when they performed each movement, their devices often swayed from the marker. In particular, when they performed rotating movements, they often lost detection because they also slightly tilted the device at same time. Meanwhile, for participants who held the devices by grabbing it from the front, their rotating movements hardly swayed from the marker.



Figure 4-17 (Top) Participant who grabs the device from the front performs a rotation without swaying from the marker while (Bottom) Participant who holds the device from the sides performs a rotation and loses detection.

However, some participants noticed this issue and tried to change the way they handled their devices. However, they changed back to their original position as it was not comfortable for them.

In terms of each movement, some participants who struggled with the rotating movements at the beginning still suffered from the same problem. Some of them even struggled more because of the pressure from the competition. Noticeably, some of the participants who struggled with the rotating movements tried to recover by rotating the device more which caused their arms to tangle while their hands obstructed the camera, and sometimes the device would move away from the marker, as shown in Figure 4-18.

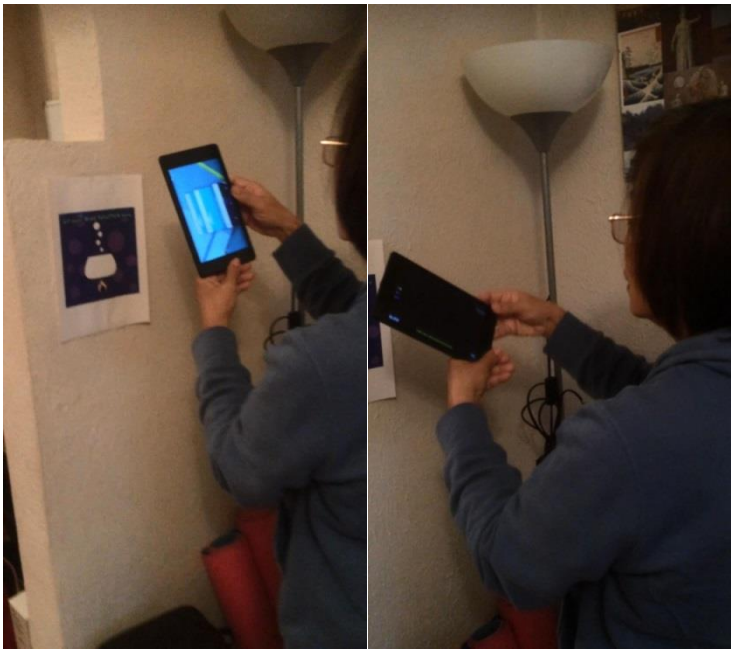


Figure 4-18 A participant tries to recover her twisted arms from rotating gestures and her hands obstruct the camera

Meanwhile, the participants who found that the tilting movements were difficult also struggled with other movements. They often lost the detection and the movements seemed to go against their natural movements when the marker lay level and they needed to tilt more, as shown in Figure 4-19.



Figure 4-19 The tilting down gesture is against their natural movements

In one of the studies, it was observed that a participant's spawn point marker came off the wall. This directly affected the participant's gameplay as he needed to stop his entire tasks to fix the marker.



Figure 4-20 A participant needs to fix his spawn point marker

At the end, most of the participants did not notice that the time was up as they solely focussed on their tasks. However, a few people were aware of the time and tried to rush the process which led to a lot more detection loss. Interestingly, all participants received similar scores no matter how well they performed.

Interview

The participants were asked to share some opinions during their gameplay. Most of them commented that the tasks were like the training session, but they felt that they were under greater pressure from the competition. Then, these following questions were asked to the participants.

1. **How easily were you able to understand the game? (rate out of ten)**
   They all gave a high score at eight to ten which means it is extremely easy to understand.
2. **Which movements did you find difficult and which ones were easy?**
   All scores given by participants were the same as in the training session.

4.3.3 Cooperative multiplayer session

The study then moved to a multiplayer session with a cooperative social scenario where participants were asked to cooperate and receive their combined scores as high as possible. The session is initially designed for players to exchange their possessed objects at the same time. Nevertheless, in the actual gameplay, it is difficult for participants in the same session to complete their personal task to possess their chemical bottle at the same time. A few participants agreed to cooperate with the players who finished first although they were actually not ready for the interactions because he was still in the middle of his personal tasks. This process normally continued until the end of session.

On the other hand, most of participants who finished later than their comrades often verbally convinced the ones who finished first to wait for them and

perform the exchanging tasks at the same time, aiming for an optimal result. This caused the player who finished faster to wait before the slower player to finish.



Figure 4-21 Participants in each session wait for their comrades to finish the personal tasks before performing their interactions

This eventually led to the event, in many sessions, that the player who finished faster tried to sneakily interact with the player who possessed his required colour without interrupting the current flow, as shown in Figure 4-22. However, most of them failed to do so and were ultimately forced back to wait for those personal tasks to finish.



Figure 4-22 The player on the left tries to sneak on his required colour that the player in the middle possesses while the two players (middle and right) are interacting with each other

It is worthwhile to note that the study session where players decided to help their comrades even without their benefit on their own tasks, always continued in this manner until the time was up. While the latter group, for a few times, agreed to help each other like the first group but this behaviour eventually shifted back to its original form. It also created different atmosphere and feelings to the players.

In one of the three-participant sessions, the player who was ready to interact with the other players, while they were not, had a strategy to improve the overall results of their sessions by peeking at the other players' screen to observe their current progress and decided whether they should complete their colour tasks first or asking for cooperation from the other participants. It showed that there is a possibility to acknowledge the other player's information by physical observations, with or without their consent, as shown in Figure 4-23.



Figure 4-23 A participant peeks on another player's screen before deciding her next moves

Three-participant sessions also show that all players could plan their movements together to optimise the process. There was one time when a player needed to interact with another participant who almost finished the tasks. However, that participant suddenly struggled with the remaining tasks and the last player finished the tasks before. They suddenly decided that they should interact with each other rather than waiting for the player who they originally intended to interact with, as shown in Figure 4-24.



Figure 4-24 A participant tries to ask her comrade for cooperation while another player comes to offer her cooperation instead

When two players interacted with each other, initially most of them performed their tasks individually and did not inform each other about their next moves.

The individual movements of the two players usually obstructed each other which resulted to a lot of detection losses. All participants eventually noticed this issue and discussed with each other to avoid the obstructions.



Figure 4-25 Two participants perform their tasks without informing each other and causes a lot of detection losses

Most of the participants used a solution where one player stopped moving and allowed their comrade to finish the tasks first then he could finish his moves afterwards. This particularly improved the speed and smoothness of the overall process. However, a few groups in some study sessions decided to perform their own tasks simultaneously by informing their current tasks and tried to find the best way to resolve both players' tasks at the same time.

Not all players were successful at these attempts. This is because the movements were mirrored and some movements when performing at the same time did not give any benefits to the other players while some movements greatly benefited from the mirrored movements. When both players, for example, are ordered to move left, their direction would be opposite and the movements benefited the whole interaction. However, when they were both ordered to move up, their relative movements seemed to be staying still and the interactions could not be completed. Some of the participants gave up after a few attempts although they tried to communicate the directions with each other, due to unfamiliarity of the movements, and went back to complete their tasks in turn. However, there was one group of participants who succeeded on this attempt and it considerably improved their overall process.

Since it seems that communication is a key factor for their cooperative gameplay. Therefore, to observe their behaviours, in a few sessions the participants were asked to play again with no verbal communication. The participants showed that they could use physical signals in the same manner as verbal conversations and their decisions and behaviours were similar. Although

the whole processes were slightly slower, the decreased speeds were not significant.

Interview

Participants were asked a series of questions as follows.

1. **What do you think about the multiplayer feature compared to the single player one?**
   Most of the participants found that the whole game was more difficult than the single player version because the cooperation required caused a lot of confusion and non-synchronised actions. They thought that teamwork was a key factor in this kind of social scenario. They were also required to think of any sudden solutions to overcome unforeseen obstacles they found. They felt the whole process was more fun than the single player version nevertheless.
2. **Which kinds of movements were difficult and which ones were easy?**
   Move in and out:
   All participants commented that these were the easiest movements to perform.
   Move left, right, up, and down:
   Some participants felt that the movements were at the same level of difficulty compared to the single player version while some participants commented that the movements were slightly more difficult as the marker were sometimes moved out against their will.
   Rotate:
   Participants found that it was easier to complete the movements, but the challenge was to keep the detection available at the entire times when performing the movements.
   Tilt:
   All participants commented that it was more difficult to complete the movements as there were a lot of detection losses when the players performed the movements at the same time.
3. **What do you think is the most important for this gameplay?**
   Participants in every session agreed that communications among players were the most important to the gameplay as the game flows improved since they realised that they should communicate with each other.

4.3.4 Competitive multiplayer session

Participants were then asked to play in the same gameplay again with a competitive social scenario instead where they competed for the highest scores among the participants in the same session. However, although they were asked to compete, they were still required to interact with the other players to proceed their tasks. The situations in the beginning of each session were similar to the cooperative setting where some players finished their personal tasks before the other players. There were several kinds of behaviours when the players who were faster tried to proceed their tasks with the other players' marker.

For the first type of behaviours, they asked the other players verbally to cooperate with them. This was successful in the beginning. Some players who were asked to cooperate temporarily abandoned their tasks to interact with those participants first without receiving anything back. However, they all eventually realised that they were competing, and they were interrupted too often. Some of them refused to interact after being asked a few times and suggested to wait until they finished or agreed mutual task exchange. Meanwhile, some players just ignored the requests and focused on their tasks without saying anything.

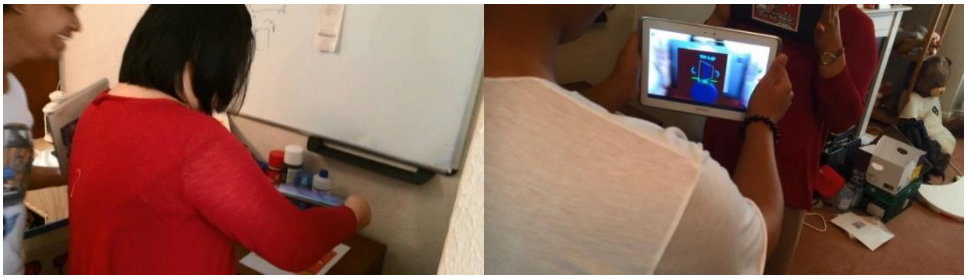


Figure 4-26 A participant waits patiently for a cooperation

For the second type of behaviours, they tried to force the other players to interact with them by blocking the other players' markers or camera. It is noted that the player with the first type of behaviours decided to do this when they needed to wait for a long time. Most of these attempts succeeded in terms of completing the tasks, but they failed later when they asked for any cooperation again. This also usually led to a minor argument. As shown in Figure 4-27, a participant tried to block the interacted marker using his whole body.



Figure 4-27 A participant tried to force another participant to interact with him

For the third type of behaviours, participants who finished the task first helped the others who were struggled to speed up their progress for their mutual benefits. However, if the benefits were not common, they usually did not agree to help, even physically blocked those attempts as shown in Figure 4-28.

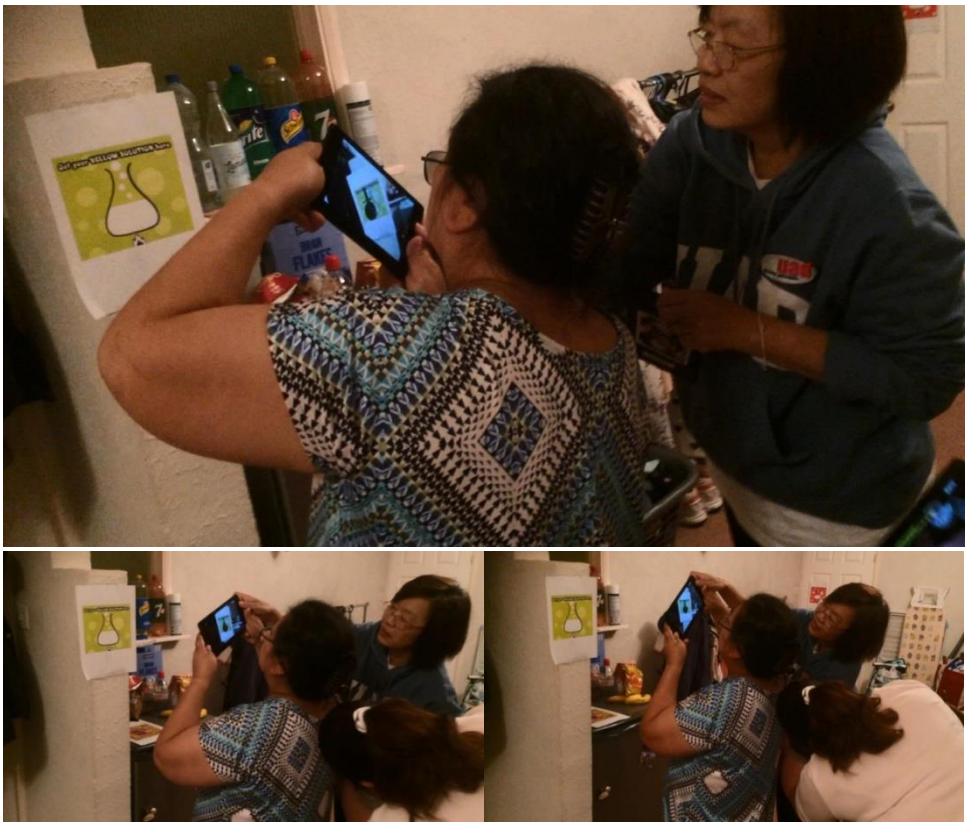


Figure 4-28 A participant helps another participant while hiding her device from the third participant

For the last type of behaviours, participants who finished first tried to sneak on the other player's marker without interrupting their tasks. This was also

intended to be a one-side benefit as there would be only one player who managed to complete the tasks, as shown in Figure 4-29.



Figure 4-29 A participant tries to sneak on another participant's marker

However, this behaviour usually failed because of two reasons. Firstly, the markers were usually not in the line of detection, or in the detectable area as discussed in the previous chapter. Secondly, it is difficult for players who were sneaking in to see their screen while sneakily performing the tasks. As a result, they did not know the current progress of their tasks.



Figure 4-30 A participant tries to sneak on another participant's marker and cannot see his own screen

Despite this, there were still many players who tried to sneak on the other player's marker even it was difficult to succeed. Figure 4-31 shows the same pair of players, as in Figure 4-29, he knew that the sneakily actions failed before, but he still tried to continue this sneaking behaviour and did this back to another player.



Figure 4-31 Participant tries to sneak back on another participant's marker

On a few occasions, a player tried to sneak on another player who was also sneaking on the third player. This chain-sneaking behaviour was usually not successful nevertheless although there were a few successful attempts. However, it fired up a more intense competitive atmosphere.



Figure 4-32 Participant C tries to sneak on another participant's marker while she is also sneaked by another player from different angles

These behaviours occurred when two players were interacting, and another player wanted to complete the tasks. They either waited, blocked, helped, or sneaked.

When two players interacted with each other, there were several times that they were betrayed even though they initially agreed to help each other. For example, there were a couple of times when one player had already finished the interaction tasks and evaded back to complete their personal tasks without waiting for their colleague to finish, as shown in Figure 4-33. This also often caused some minor arguments among players.



Figure 4-33 Participant moves away after finishing his tasks without another player's consent

Some players tried to obstruct the actions of their partner, either by obstructing the marker or blocking the camera directly, as shown in Figure 4-34. This always caused mirrored actions, which meant that nobody could complete the tasks, and they were eventually forced back to cooperative interactions for their benefit.



Figure 4-34 Both participants cover their markers to prevent the others to finish the tasks

As they were pressured from the competition, participants tended to interact quickly unlike the cooperation scenario. It caused a lot of detection losses and the overall scores were lower than the cooperative session.

Finally, yet importantly, in the session where the participants knew each other quite well, it was found that they tended to be more competitive with each other than in the session where the participants were not familiar with each other. This supports the review in Chapter 2 stating that pre-relationships are one of the factors in multiplayer games, but it is beyond the game design's power.

Interview

They were asked a series of questions as follows.

1. **What do you think about the competitive scenario compared to the other scenarios?**
   Generally, participants commented that the game was much more difficult than the other scenarios but also much more fun as the game could bring unexpected outcomes. However, they realised that it was impossible for all players to detect all markers at the same time. This required good skills and good timing along with negotiation skills. However, overall, they needed to maintain the cooperative movements when achieving a competitive purpose.
   They were asked to rate the difficulties and enjoyment of the three social scenarios: single player, cooperative multiplayer, and competitive multiplayer. All participants in all sessions agreed that the competitive multiplayer scenario was the most difficult, followed by the single player and cooperative multiplayer scenarios. Competitive multiplayer was also the most enjoyable, followed by cooperative multiplayer and single player scenarios.

2. **Which movements were difficult and which ones were easy?**
   All participants agreed that the order of difficulties remain the same, but overall difficulties were significantly higher.

4.4 Discussion

This series of studies has revealed a lot of valuable information in user experience, decisions, behaviours, concerns, etc. in a face-to-face augmented reality game topic. However, in this discussion session, the findings on decisions or behaviours will not yet be discussed. This session focuses on the findings of any possible improvements or unforeseen emerging concerns. This aims to expand the scope of further research study in face-to-face augmented reality games. The findings on user experience, participants' decisions, comments, and behaviours will be discussed later in Chapter 6.

During cooperative multiplayer sessions, most of the participants decided to use verbal communications to inform each other and allowed each participant to finish the tasks one at a time. However, on some occasions, participants decided to perform their tasks simultaneously. Although it was not successful most of the time, these attempts revealed interesting players' behaviours and strategies.

Firstly, these simultaneous movements created confusion for the players. The players faced each other, and their directions were mirrored. There were some

movements in six degrees of freedom, which meant that they moved in the same direction such as moving up and down. However, most of their movements were in opposite directions such as move left / right or rotating device clockwise / counter-clockwise. It caused the players to think of the movements from their partner's point of view which is problematic and confusing. Most of the participants in this series of studies gave up their attempts eventually and shifted back to the one-by-one movements instead. This is because the latter movements were more understandable and easier to perform, especially in time-pressuring situations. However, there were also a few people who succeeded in their attempts which led to speed improvements.

Secondly, these simultaneous movements revealed another issue in relative movements of the two players. Considering that one player can perform thirteen movements in six degree of freedoms: stay still, move left, move right, move up, move down, move in, move out, rotate clockwise, rotate counter-clockwise, tilt left, tilt right, tilt up, and tilt down, therefore, combining the movements of two players, there should be 169 movements in total, as shown in Table 4-1.

		Still	Transitions						Rotations					
			X (+)	X(-)	Y(+)	Y(-)	Z(+)	Z(-)	Roll (+)	Roll(-)	Yaw(+)	Yaw(-)	Pitch(+)	Pitch(-)
Still														
Transitions	X (+)													
	X(-)													
	Y(+)													
	Y(-)													
	Z(+)													
	Z(-)													
Rotations	Roll (+)													
	Roll(-)													
	Yaw(+)													
	Yaw(-)													
	Pitch(+)													
	Pitch(-)													

Table 4-1 Table of combined movements between two devices

However, there are some combined movements which produce ambiguous relative movements. For example, when one player moves left, and another player moves right. The relative movement is too vague to distinguish. In the worst-case scenario, if two players move at the same speed, the movement detected in the observer's frame is they are staying still. This happens in many combined movements, as shown in Table 4-2.

		Still	Transitions						Rotations					
			X (+)	X(-)	Y(+)	Y(-)	Z(+)	Z(-)	Roll (+)	Roll(-)	Yaw(+)	Yaw(-)	Pitch(+)	Pitch(-)
Still		X	A	A	S	S	A	A	R	R	/T\	/T\	/T\	/T\
Transitions	X (+)	A	A	X	C	C	A	A	C	C	C	C	C	C
	X(-)	A	X	A	C	C	A	A	C	C	C	C	C	C
	Y(+)	S	C	C	S	X	C	C	C	C	C	C	C	C
	Y(-)	S	C	C	X	S	C	C	C	C	C	C	C	C
	Z(+)	A	A	A	C	C	X	A	C	C	C	C	C	C
	Z(-)	A	A	A	C	C	A	X	C	C	C	C	C	C
Rotations	Roll (+)	R	C	C	C	C	C	C	R	X	C	C	C	C
	Roll(-)	R	C	C	C	C	C	C	X	R	C	C	C	C
	Yaw(+)	/T\	C	C	C	C	C	C	C	C	/T/	/T\	/T\	/T\
	Yaw(-)	/T\	C	C	C	C	C	C	C	C	/T\	/T/	/T\	/T\
	Pitch(+)	/T\	C	C	C	C	C	C	C	C	/T\	/T\	/T\	/T/
	Pitch(-)	/T\	C	C	C	C	C	C	C	C	/T\	/T\	/T/	/T\

Table 4-2 All possible combinations of relative movements

X – This relative movement does not cause any changes in visual detections.

A – Devices are moving in parallel in different directions on the screen. The relative movement is interpreted as the observer's device is moving in plus or minus directions.

S – Devices are moving in or out. The relative movement is interpreted as the observer's device is moving in or out of the other side.

R – Devices are rotating around the Y axis. The relative movement is interpreted as the observer's device is performing a roll rotation gesture in clockwise or counter clockwise directions.

/T/ – Devices are tilting in the same direction. Therefore, at a certain point, two devices would be in a parallel gesture, like gesture A. The relative movement is interpreted as the observer's device is moving in plus or minus directions.

/T\ – Devices are tilting in a different direction. The relative movement is interpreted as the observer's device is tilting.

C – More than one type of movements is performed at the same time. Movements are complicated and independent. The relative movement is interpreted per each individual movement.

Moreover, as the combined movements are considered only vision-based, it sometimes cannot recognise which one of the two devices is moving, or both. For example, when a relative movement comes from one side, it is assumed that

the detected marker on his partner's device is moving right. In fact, it is possible that the observer is moving left while his partner is staying still, his partner is moving to his left while the observer is staying still, the observer is moving left while his partner is moving to his right but slower than the observer, the observer is moving right while his partner is moving to his left but faster than the observer, or the observer is moving left while his partner is moving to his left. This ambiguity occurs commonly and prevents the players to perform some decisions. It also possibly limits many kinds of possibilities in face-to-face augmented reality gameplays.

Therefore, this issue will persist in the next chapter to expand the scope of study in face-to-face augmented reality games greatly.

4.5 Conclusion

This chapter covered a lot of elements in a practical face-to-face augmented reality system study. Firstly, a prototype of a face-to-face augmented reality game was derived from the games which were designed in the series of workshops in Chapter 3. The game itself adopted advantages from the three games and was designed to rely on physical movements while being flexible in both single player and multiplayer settings. This game is one of the first examples of face-to-face movement-based augmented reality games.

A user experience and behaviours study were designed around this designed game. The study was designed to maintain the advantage points of physical movements and a face-to-face augmented reality game while giving a suitable learning curve to players. It was expected that this study will uncover any unforeseen user experience and user behaviours of face-to-face augmented reality games.

The studies were conducted six times. Each study was run with two or three participants each time. Fifteen participants in total took part in the study. All participants had some experience either in computer science, augmented reality, or computer games. Some of them had experienced augmented reality before but some of them did not have any previous augmented reality applications. The ages of the participants ranged from 23 years old to 60 years old. The experiments were run in a medium-sized room with a good lighting condition. The markers used in the study were printed clearly and attached to their places in the room. The user behaviours were recorded by one main camera to capture the overall game flow and a few small cameras at each player's station to capture individual behaviours.

There are four main sessions in the study, which are introduction and training, single player, cooperative multiplayer, and competitive multiplayer. Each

session reflects many user behaviours in each scenario. It seems that user experience is affected directly from user behaviours which are influenced by the given scenario. This includes how participants perform a movement and how they interact with each other, which is the essential part of face-to-face augmented reality games.

This series of studies also reveals some concerns in face-to-face augmented reality games where relative movements of two facing players create ambiguities and confusions. This can hinder several possibilities in the topic. This issue will be further investigated in an expanded scope of the research in Chapter 5. On the other hand, the participants' opinions and user behaviours from the study in this chapter is going to be discussed in Chapter 6 along with the observations from the extended studies in Chapter 5, which is expected to expand the knowledge of face-to-face augmented reality games further.

Chapter 5

Further study of face-to-face augmented reality games including device sensors

In Chapter 4, a series of studies in the face-to-face augmented reality game topic was conducted which revealed several key issues. One issue that has emerged from the studies concerns ambiguities in face-to-face interactions between two players in the game because of mirrored actions and relative movements which leads to confusion among them. The current chapter, therefore, extends the study from the previous chapter to address this issue. The technology is now extended to use onboard movement sensors to capture additional degrees of freedom of movements of handheld displays and the previous study is re-designed and conducted with additional participants. This new study further expands our understanding of face-to-face augmented reality game studies and reveals how different sensing modalities affect players' behaviours and experiences which will be further discussed in Chapter 6.

5.1 Study concept and objectives

The studies in Chapter 4 revealed several interesting behaviours and experiences of players in face-to-face augmented reality games in different social scenarios. At the same time, it revealed ambiguities of face-to-face interactions due to mirrored actions and relative movements. This need not be a fundamental limitation of face-to-face augmented reality games, but instead can be either a feature or an obstacle solely depending on the design of gameplay. This can be an expansion of possibilities in face-to-face augmented reality games and affects user behaviours and experiences. Therefore, it is worthwhile

to expand the scope of study into observations on face-to-face augmented reality games with or without these ambiguities.

To recapitulate from the previous chapter, there are ambiguities around some face-to-face interactions when relying on only visual tracking of the other players. For example, detecting the marker of the partner to be moving right can be caused from player's movements in any direction. It seems that to distinguish these combined movements, some more information is needed from each player.

Some can say that data transmissions between two devices, whether via cable, Wi-Fi, Bluetooth, etc., are essential for multiplayer games to give a common information to all players. However, there are also a lot of multiplayer games that involve no data transmission, yet still produce a good multiplayer gaming experience, e.g. Johann Sebastian Joust (Wilson, 2011). Considering a real-world situation where two players are facing each other: each player acknowledges the current situation without verbally asking for the opponent's state. At each point of time, each player requires the current position and orientations of the opponent relating to him through vision. Meanwhile, he also knows his current orientations and the directions he is moving. These pieces of information are enough to determine the current state of two players in a multiplayer game.

I propose that this is the same as in face-to-face augmented reality games where they try to imitate real-world face-to-face situations. Additional required information, apart from relative movements from visionary observations, is self's orientations and directions which can generally be obtained from various internal device sensors. These pieces of information should be sufficient to distinguish all ambiguous combined movements from the previous chapter.

In this chapter, the study in previous chapter will be extended to include information from internal device sensors. The study will focus on how this additional information affects user experiences and behaviours. Like in the previous studies, observations are conducted in different social scenarios to investigate player's decisions in different situations. Participants of this study are observed from different perspectives, like the previous studies, including actions, multiplayer interactions, and overall gameplay.

5.2 Study design

In this section, the game used in the study and study plan will be presented. The format of this study was altered from the series of studies in the previous chapter by including information from device sensors and take those pieces of information into consideration in the gameplay.

5.2.1 Alteration of studied face-to-face augmented reality game

The face-to-face augmented reality game, that was used to be studied in the previous chapter, only relied on computer vision technology and did not include any data from sensors. To expand the scope of study over the relative movement ambiguities, this 'chemical-delivery' game will be altered to include additional data to the gameplay.

The data appended into the gameplay is from the device sensors: a gyroscope to recognise the device orientations and an accelerometer to recognise the directions of movements. These pieces of data are incorporated into the gameplay to acknowledge the current state of the device which was neglected in the first build of the game.

The gameplay is simplified to be a two-player version instead of a three-player version. This is because this study will focus on the performance and interactions between two players without any interruptions. The context of the game, where players are required to deliver chemical solutions which leads to interactions with several markers, is also removed from the gameplay to simplify the game flow. There is only one type of marker in the gameplay which is attached to the back of each device to track the movement of each player. The marker used in this gameplay is the same pattern as the marker used in the training session in the previous studies. Since there is no context in the game, it is not necessary to use a specific pattern of marker and this marker is a default Vuforia marker, which is one of the most detectable markers.



Figure 5-1 Marker in training session

The game is initially set as in Figure 5-2.

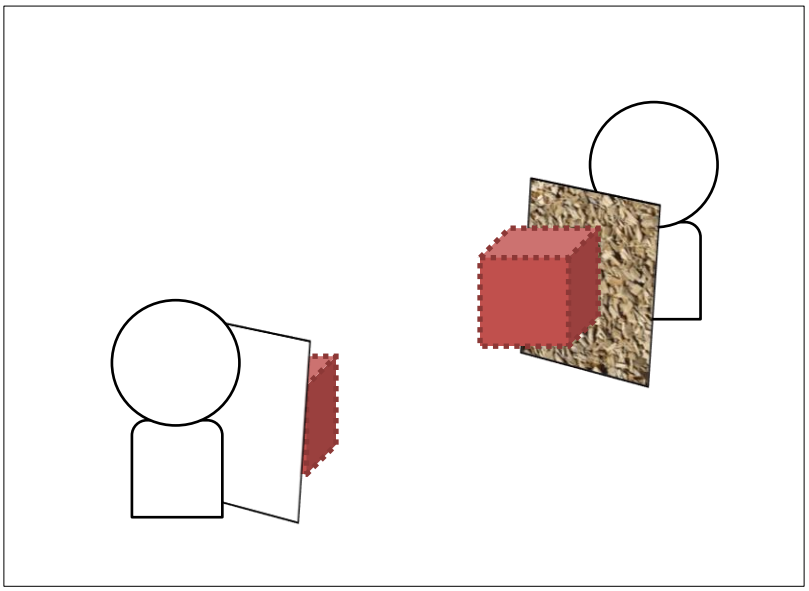


Figure 5-2 Game initial setting of the gameplay with virtual objects in dash line

The game flow starts with demonstration of required movements that each player needs to perform at the centre of the screen. The movements are basic relative movements in six degrees of freedom. This is similar to movements that players performed together in the previous studies, as shown in Figure 5-3. However, there is one more movement added to the list, that of staying still for three seconds, which therefore means that there are thirteen movements in total. Once each movement is performed, the score increases by one. Each player has five minutes to get the highest scores.

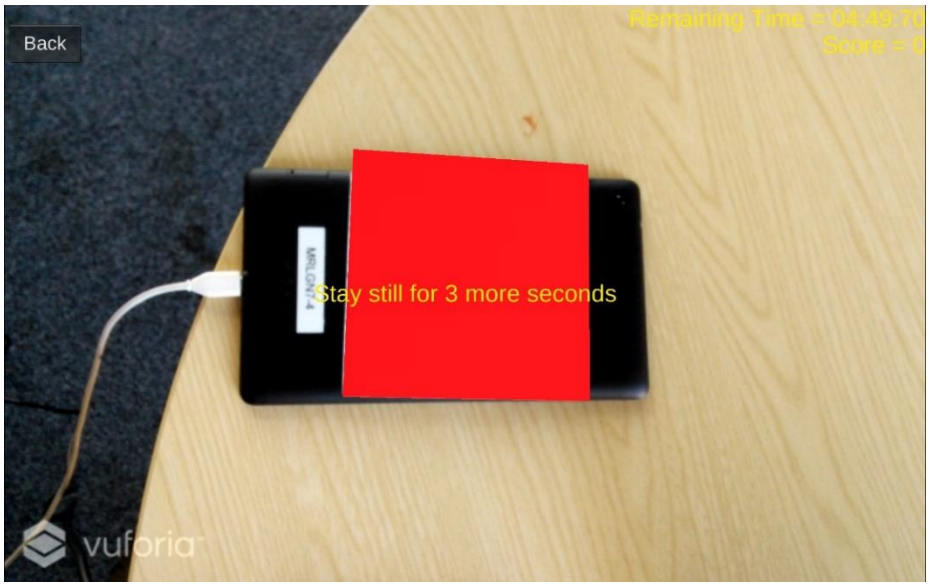


Figure 5-3 Movements required are shown at the centre of the screen

However, from the second minute of the gameplay, there will be additional rules delivered to the player. These rules are applied to the movement of the player's device using information from the gyroscope and accelerometer to detect the movements and orientations. The list of the rules created with data from device sensors is shown below.

Rule	Involved sensors
Do not move your tablet	Accelerometer and Gyroscope
Keep moving left or right	Accelerometer and Gyroscope
Keep moving up or down	Accelerometer and Gyroscope
Keep moving back or forth	Accelerometer and Gyroscope
Keep turning left or right	Gyroscope
Keep facing upward or downward	Gyroscope
Keep rotating your tablet	Gyroscope

Table 5-1 Rules of movement and their involved sensors

These are the rules of movement that each player must follow in the game. If the player does not follow the rule, the colour of the restriction text will turn red and any scores during this time will not be applied. On the other hand, if the rule is followed, the colour of the text will turn green and the scores will be added up normally. These restrictions will be changed from time to time until the five-minute period is up.



Figure 5-4 (Top) Restrictions are not followed and the text turns red (Bottom) Restrictions are followed and the text turn green

The rules will be shown at the centre of the screen for a few seconds before moved to the bottom right corner of the screen.



Figure 5-5 Rules of movement are shown at the centre of the screen

This concludes the design of revised version of face-to-face augmented reality game that being used in the study.

5.2.2 Study plan

The plan for this study broadly corresponds to that of the previous series of studies. This intends to bring similar setting up with appended features to observe the user behaviours, decisions, and experiences in similar situations.

First, participants are asked to perform training in a training session to familiarise with the movements in the game just like the previous series of studies, followed by two major social scenarios in the study, which are competitive and competitive multiplayer, to explore a key relationship which might affect the user experience. Participants are asked to play a face-to-face augmented reality game and their actions, reactions, decisions, and behaviours are recorded. After that, they are asked to attend interviews about their experiences.

These four sessions are now explained in greater detail.

Introduction and training session

This session is designed to establish a good mutual understanding of face-to-face augmented reality to participants. Some examples of augmented reality systems are presented, and the research objectives are introduced. Participants also have an opportunity to practice their movements until they are confident before continuing to further sessions.

The screen of the system used in this training session is simplified. There is only a primitive cube object, augmented to the marker to indicate that the marker is detected. A series of required movements is sent to a player to perform and this series is in a loop where the player can stop when he is confident.

The screenshot of the user interface is presented in Figure 5-6.

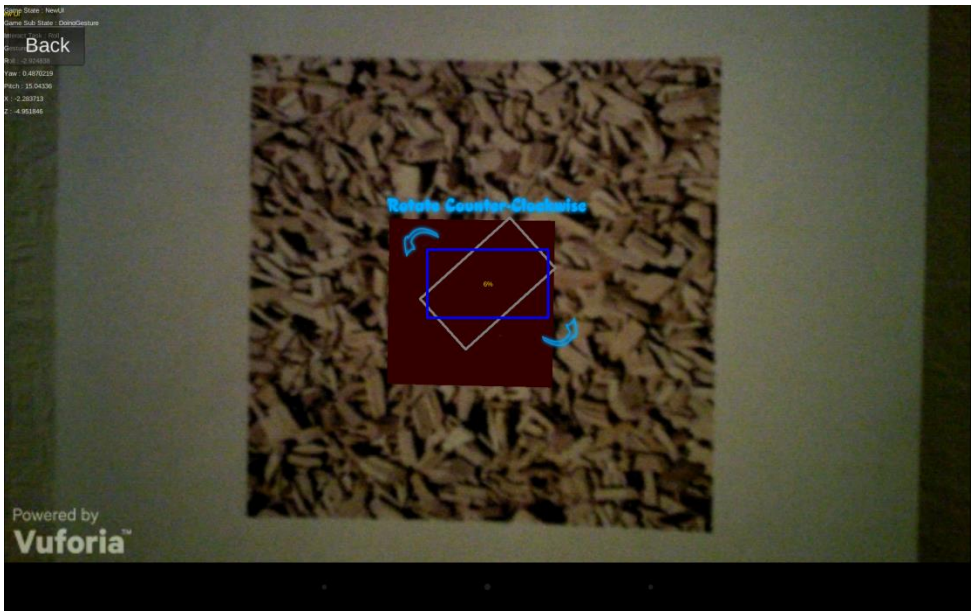


Figure 5-6 Training session interface

After they finish the training session, they progress to the actual game part with a competitive multiplayer mode.

Multiplayer - competitive session

After the training session has finished, a multiplayer session with a competitive setting is introduced. This is different from the previous studies where participants were asked to cooperate with each other before competing in those studies and they tended to communicate with each other more as time passed, which is the key factor of cooperative scenarios. Therefore, it is more sensible to ask participants to compete first, then ask

them to cooperate which leads to more communications when they know each other better. Participants are asked to perform movements with the gameplay described above and deliver the highest individual scores possible within a time limit of five minutes. They are encouraged to talk with each other so as to plan any tactics or strategies to enhance their situation.

After that, participants are asked to give their opinions about their experience when playing the game. First, they are asked to give their opinions about how they find their experience compared to when they perform the movements individually during the training session to retrieve the data of user experience of a multiplayer play setting.

Secondly, participants are asked about their opinions of each movement that they performed during gameplay and to rate the movements from zero to ten, where zero is the hardest to perform and ten is the easiest to perform.

Participants are also asked to explain on their interesting behaviours during the session, or what they were thinking when they made those decisions. This is a good material to understand the player experience. After this, the study proceeds to multiplayer with a cooperative setting.

Multiplayer - cooperative session

After the competitive multiplayer session, the study continues to a multiplayer session with a cooperative setting. Participants are invited to play the game as the previous session. However, they are also asked to cooperate with each other to deliver the highest combined scores as possible. They are informed the top scores from the other session to encourage them to beat the statistics. This is to encourage them to work together and build a plan to deliver the best results within the restrictions and time limits.

In this session, as before, participants are asked to give their opinions about their experience after playing the game. Firstly, they are asked to give their opinions about how they find their experience comparing to the competitive multiplayer version to retrieve the data of user experience of a multiplayer play setting. Secondly, participants are asked to share their opinions on each movement they performed during gameplay and rate the movements from zero to ten where zero is the hardest to perform and ten is the easiest to perform the same as the competitive multiplayer session, as it is anticipated that the social scenario would affect the movements as well as how the restrictions which are applied on those movements affect user experience in different social scenarios.

Participants are also asked to explain on their interesting behaviours during the session, or what they were thinking when they made those decisions, like in a competitive multiplayer session.

Conclusion session

After all sessions are played, participants are asked to give their final opinions. They are asked about all social scenarios and rate the degrees of enjoyment on each scenario from zero to ten, where zero is the least enjoyment and ten is the most enjoyment. They are also asked for any experience they find interesting while playing in each session. After that, they are asked about their final thoughts of this game mechanics on any game it could be applied to. Also, they are asked about their idea on face-to-face multiplayer augmented reality games. That concludes the study.

5.2.3 Other important study components

These are the other important components for the study.

Study venue

An indoor room with a suitable light condition for an augmented reality system.

Expected participants

To maximise the study data, participants should be anyone who has any of these attributes: -

- Interested in augmented reality
- Have related computer field backgrounds
- Related in computer games development
- Often play games

Number of participants

Two participants per study.

5.3 Study results

The study has been conducted after it is revised from the previous series of studies. The main objective is still to observe the player's behaviours, decisions, and experiences which would benefit face-to-face augmented reality game design. In this section, those observations and the interviews will be presented in detail before being further discussed in the next chapter. Like the previous study, some basic information of the studies will be explained below.

Basic information of the study

This series of studies have been conducted seven times, two of which are pilot studies and five of which are actual studies. All seven studies will be presented together because their structures are similar and the observations on the pilot studies also provide some thought-provoking issues.

There are two participants in each study. Participants are between 18 to 35 years old. All participants have backgrounds in either computer science or games. However, not every participant has previous experience of augmented reality technology. Some participants might have heard about the technology, but had never tried it before while some participants had never heard about it.

There is only one type of devices used in this study which is Google Nexus 7s (2013) running on Android 5.1. The studies are conducted in room with suitable lighting to avoid troubles on image detections during the studies.

The results will be presented below in each session of the study.

5.3.1 Introduction and training session

Initially, participants struggled with how the physical augmented reality movements worked. However, they eventually familiarised themselves with the system after some explanation.

5.3.2 Competitive multiplayer session

The study then moved to a multiplayer session with a competitive social scenario where participants were asked to perform their best and compare their final scores at the end to create a competitive atmosphere between them

Most of participants did not talk or communicate with each other. They focused on their personal tasks and tried to increase their speed to maximise their scores. However, some of them changed their behaviours when the time passed. They tried to observe their opponent's movements instead of moving aimlessly. Some of the participants waited until they saw the movements which benefited their tasks, they then started moving.



Figure 5-7 Participant on the left waits until he sees movements that benefit his tasks

Some participants investigated and tried to move to match those movements in the way that support their tasks, which caused some uncomfortable movements, as in Figure 5-8 and Figure 5-9.

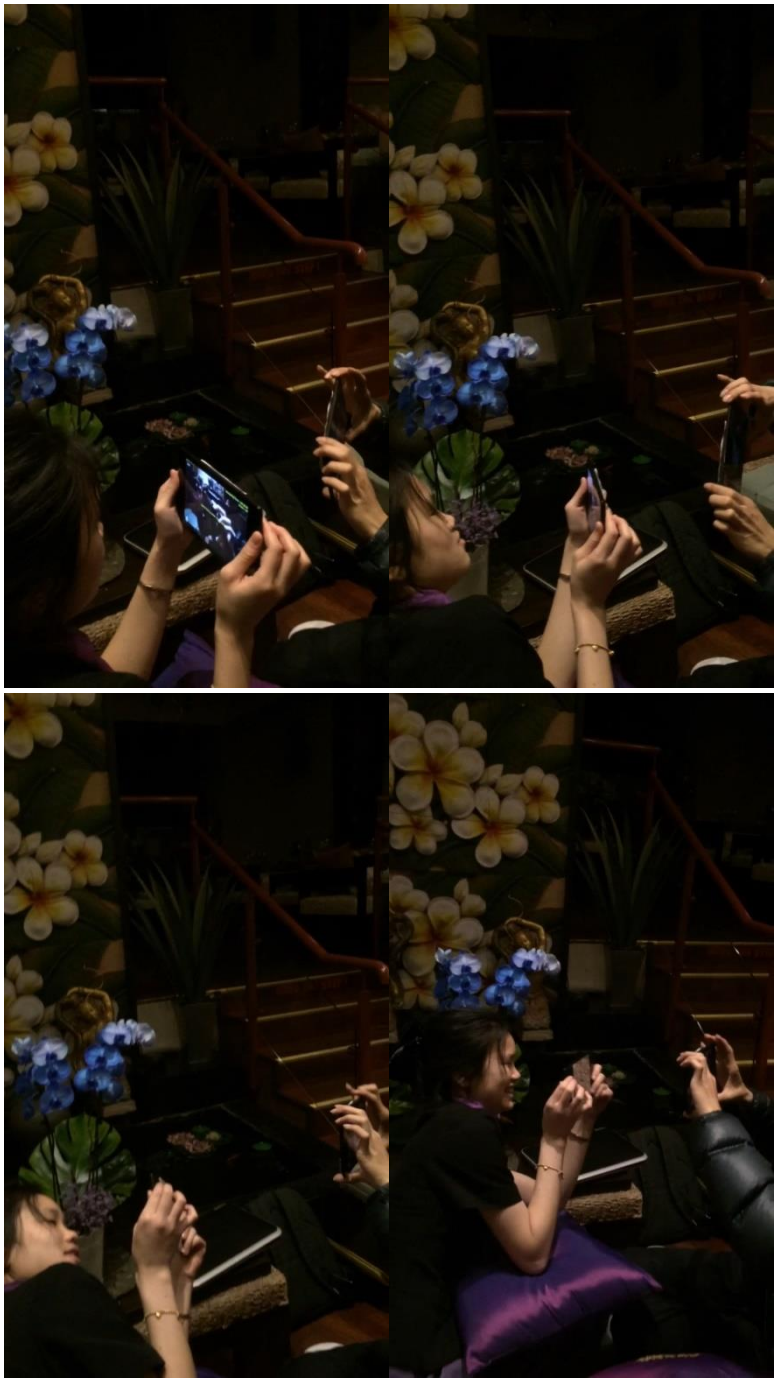


Figure 5-8 Participant on the left tries to move just her upper body to match her opponent's direction, eventually requires her to move the whole body instead



Figure 5-9 Participants try to rotate their device to match their opponent's movements

However, even when they focused on their opponent's movements, it seems that they only focused on the marker at the back of their opponent's device – not the existence of their opponent or environment. This is because both players sometimes tried to move to match the opponent's movements and they realised later that those movements were impossible. For example, players in Figure 5-10 moved the devices upward and downward at the same time and realised later that they were at the limit of their body movements.



Figure 5-10 (Top) Two players move their devices upward without noticing that it is out of their reach (Bottom) A comparable situation occurs when they move downward

Another example was when players in Figure 5-11 moved out at the same time and did not realise their environment which caused them to hit the wall of the room.



Figure 5-11 Players move out and hit the wall of the room

Despite of these issues, these people generally got higher scores than the participants who did not observe opponent's movements.

One clearly noticeable issue was *staying still*, which was the enhanced movement in this series of study that caused a lot of frustrating moments to participants. The movement required players to keep the marker on the screen to stay still for three seconds or the timer would be reset back to three seconds again. However, since the speed of the two players normally was not entirely equal, there were some overlapping movements on each side. This made staying still difficult to execute. In the study, this task was like an anchor point of both players' movements where two players paused their motions. It was difficult for a player to execute this task while his opponent kept moving although he moved at the same speed and in same direction as his opponent. This irritated a lot of the participants as they could not easily complete this task. Some showed their

frustration through their movements or conversations. One participant was so frustrated that he tried to move as close to his opponent's device as he could as if he wanted to stop the movements.



Figure 5-12 A player tries to stop his opponent's movements by moving in as close as he can to his opponent's device

In some sessions, players agreed to both stop moving to complete the staying still task first. However, the players who finished first tended to start moving immediately after they finished their own task, which caused their opponent's timer to reset. In one session, both players agreed to cooperate in staying still, but one player tried to move his device a little with an intention to secretly reset his opponent's timer.

On the other hand, most of the behaviours which were caused from the movement tasks were still noticeable. For example, rotating, which is one of problematic movements, also caused troubles to some participants. One participant even rotated in a full round to complete the task.



Figure 5-13 A player has troubles with rotating, similar to the previous study

From the second minute, a rule of movements was presented to participants randomly and it was changed every thirty seconds. Some participants noticed it and tried to follow the rules while the others did not notice the rules at all. In the session where both participants noticed and followed the rules, they sometimes temporarily cooperated with each other until the rule was changed. As in Figure 5-14, both players tried to follow the rule "keep moving left or right" which leaded to both players executing the tasks while walking in a circle.



Figure 5-14 Two players executes the tasks while walking in a circle to follow the rule "keep moving left or right"

However, some players who tried to follow the rule eventually gave up as they noticed that there was no penalty for not following the rules. However, their

scores did not increase as fast as when they tried to follow the rules. There were a few players whose scores did not increase at all after the second minute.

The last interesting point was, as mentioned before, participants normally did not recognise the existence of their opponent even when their movements sometimes support each other coincidentally. However, when their movements obstructed each other, they began noticing the opponent starting from the marker, then the arms, and the whole body.

Interview

Participants were asked a series of questions as follows.

1. **What do you think about this setting of augmented reality games compared to the typical ones?**
   Most of the participants stated that it was more fun, but also more difficult at the same time. Some said that most of the augmented reality games are point and click games while this setting requires the whole-body movements. Some stated that they felt their movements had objectives and meanings, which created great feelings for them.

2. **Which movements were difficult, and which ones were easy?**
   All participants agreed that moving left / right / up / down / in / out were equally easy to perform. However, while there could not agree whether rotating or tilting were the most challenging task to perform, some stated that staying still was also difficult. Some participants even mentioned that staying still was the most challenging task to perform.

3. **How did you feel about performing the movements under the rules?**
   Some participants noticed the rules and they found it was hard to follow the rules while performing the tasks at the same time. Some noticed them but did not pay attention to them. A few participants did not notice the rules at all.

5.3.3 Cooperative multiplayer session

Participants were then asked to play in the same gameplay again with a cooperative social scenario where they helped each other to maximise their combined scores. Their combined scores were compared with the other group to motivate them to do their best.

In this social scenario, it was obvious that participants communicated with each other much more than in a competitive scenario. However, each group of players displayed different strategies to optimise their movements. These strategies can be divided into three main groups.

The first group displayed turn-by-turn actions. They executed one task at the time, waited until their partner finished, and the loops repeated. These groups executed their tasks perfectly and many of these groups tried to optimise every action. It was often found that one player in each group acted as a commander. However, because they needed to consider every possible movement, they occasionally required to pause and think of a solution, as shown in Figure 5-15.



Figure 5-15 One player pauses and thinks before commanding the next moves

As they tried to execute every task perfectly, sometimes they were required to make gestures which followed the rules of movement and led to uncomfortable and redundant movements. For example, in Figure 5-16, they tried to follow the rule “keep facing upward and downward” but they did not know if the task in the lower device was executed properly. Therefore, they needed to switch their position in turn and wasted a large amount of time.

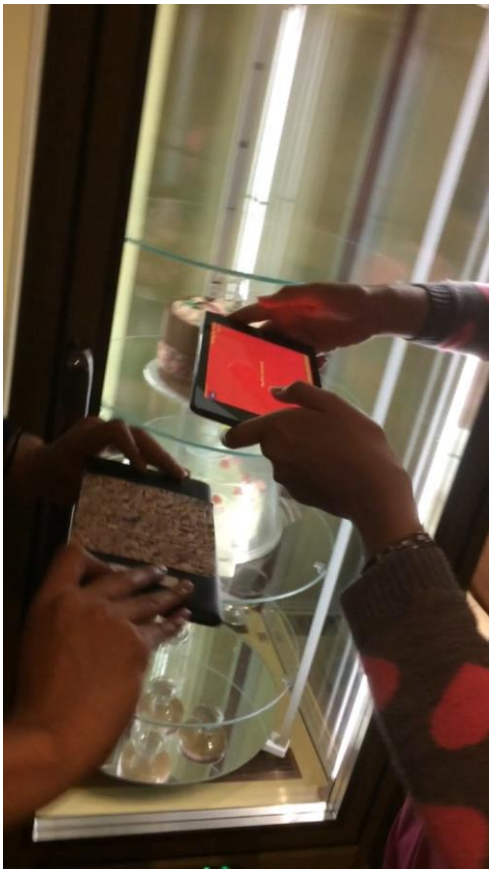


Figure 5-16 Participants try to follow the rules of movement perfectly

Nonetheless, in general, the speed of these groups was low compared to the other groups.

The second group displayed synchronised actions by performing their tasks simultaneously. They gave their signal for their current tasks, which was normally the same as the partner's tasks because they did the tasks together. This type of playing was difficult to achieve, and many groups tried at the beginning and then gave up. Only one group successfully used this method and got the highest combined scores among all groups. They tried their best to perform the tasks at the same time and as smoothly as possible. As shown in Figure 5-17, two participants were performing the "tilt right" task when suddenly the rules of movement changed to "keep moving left or right". They transferred their movements smoothly.



Figure 5-17 Participants transferred their movements smoothly when the rules of movement changed

The last group, which contains the biggest number of groups, displayed hybrid actions between the first two groups. They performed the tasks on their own and asked their partner to help when required, normally at “stay still” and “tilt” tasks which were difficult to perform alone. However, although they only asked for help only when required, they still continuously communicated.

Some of the behaviours in a competitive scenario were also displayed by this group. For example, in one group in Figure 5-18, the participant paused and waited for her partner to move into her benefit without informing her partner about her break.



Figure 5-18 Participant on the left paused and waited for the movements that benefit her without informing her partner

One thing that is worthwhile to mention is that players in this cooperative scenario could fully recognise the existence of their partner and the environment and responded as if they were in the real world. This also involved continuous communication between players. However, there were some points that participants reported that when something inconsistent with the real world occurred, it broke the immersion. For instance, players in Figure 5-19 moved their devices close to each other and could not detect the marker although their devices were directly facing. This was because the position of the camera of the device is on the left edge of the device and the marker was moved out of the detectable area when devices were moved too close to each other. They needed to move the device a little to the right-hand side which conflicted with the real-world feeling.

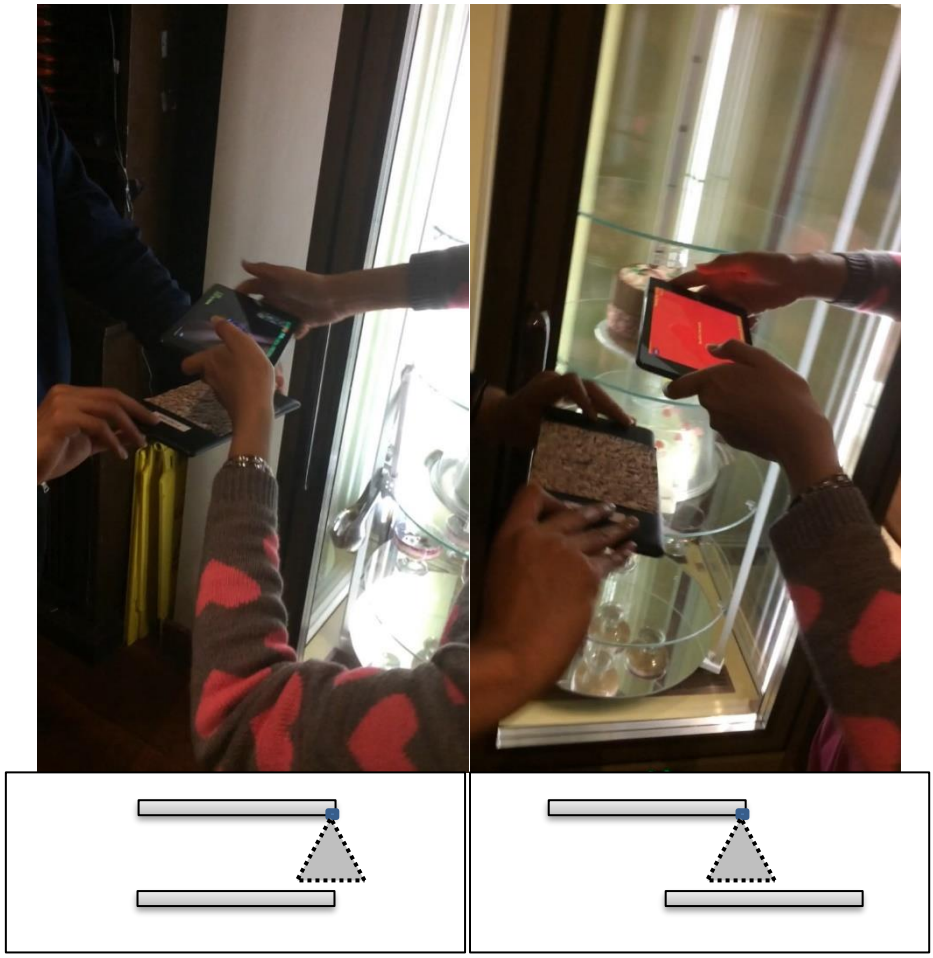


Figure 5-19 (Top) Participants must move their devices out of the pararel line to detect the marker again due to the position of camera which creates an inconsistent feeling (Bottom) Detectable area of the device when they move close to each other

In terms of the rules of movement, unlike in a competitive scenario, participants in every group recognise the rules and tried to follow the rules as much as possible. In a competitive scenario, participants normally scored in the first minute where there were no rules more than in the last four minutes. However, in a cooperative scenario, they scored in the last four minutes more than the competitive one. In some sessions, participants scored almost the same level as the first minute with no rules.

Interview

Players were asked a series of questions as follows.

1. **What do you think about the cooperative scenario compared to the competitive scenarios?**
   They felt that they could perform the tasks better this time because of the communication. They also reported that they thought the competitive

scenario was more fun than cooperative scenario. This is similar to the previous studies.

In the sessions where participants tried to perform the tasks perfectly (the first group which was described in the previous session), they reported that they felt that the game was easier in the first minute without rules. However, the game was more difficult in the last four minutes with rules, although they scored more. These might be because they tried to perfect every single movement which required to consider from the two perspectives at the same time. However, the rest of the participants stated that all tasks were easier, and they did not feel any difference from the tasks with or without the rules of movement, unlike in the competitive scenario.

2. **Which movements were difficult, and which ones were easy?**
   All participants agreed that the order of difficulties remain the same, but overall difficulties had decreased hugely, including the staying still movement. They now felt that staying still was much easier. Some groups stated that staying still was the easiest task to complete.

5.4 Conclusion

This chapter presented an expansion of the face-to-face augmented reality game study in Chapter 4 by considering information from onboard device sensors to capture additional movement data. The game in Chapter 4 has been simplified and enhanced with the data from a gyroscope and an accelerometer. Apart from a list of tasks which are movements in six degrees of freedom like in the previous chapter, a set of movement rules has been added to the game for players to follow. These rules are considered using sensor data unlike the tasks which are considered using visionary information. These are expected to avoid the ambiguities found in the previous chapter and display some more interesting user behaviours and experiences.

The study was conducted with seven pairs of players. All participants have some experience either in computer science, augmented reality, or computer games. Some of them have experienced augmented reality before but some of them did not try any augmented reality applications. The age of participants ranged from 18 years old to 35 years old. The experiments were run in a medium-sized room with a good lighting condition. The markers used in the study were printed clearly and attached at the back of each device. The user behaviours were recorded with one main camera to capture the overall game flow and a few small cameras to capture individual behaviours.

There are three main sessions in the study which were introduction and training, competitive multiplayer, and cooperative multiplayer. Each session reflects

many user behaviours in each scenario. Initially, ambiguities in face-to-face augmented reality were removed by the sensor data as it was observed that participants successfully executed different ambiguous tasks in the previous studies correctly with the help of the rules of movement. However, the usage of these rules of movement in different social scenarios were also observed. This is useful for face-to-face augmented reality games design.

The study provided several additional issues in face-to-face augmented reality games. Participants seemed to be unaware of their constraints in both their range of movements and surroundings when they focused on completing the tasks. Staying still becomes one of the most challenging movements for players when they played in a competitive setting. However, this movement became an extremely easy task when they communicated with each other. An inconsistent feeling was also revealed at the point of moving too close to each other and when the position of the camera and the marker was not at the expected position. Apart from these, several points in user experience were comparable to the study in Chapter 4.

Points from studies in Chapter 4 and 5 will be discussed in the next chapter in various aspects of the topic. The upcoming discussion aims to establish knowledge for face-to-face augmented reality game design in the future.

Chapter 6

Discussion

The previous chapters have shown how multiplayer augmented reality games can be enhanced with face-to-face interactions. The topic has been pursued through an initial feasibility study and a further series of two user experience prototyping and behavior studies. These studies have revealed several previously issues in face-to-face multiplayer augmented reality games that are worthy of a more comprehensive discussion. In particular, they reveal the characteristics, feasibilities, possibilities, and expectations of the face-to-face actions in a multi-user setting, which could lead to the improvement of multiplayer augmented reality games that is the purpose of this thesis. In this chapter, these issues will be discussed so as reveal wider knowledge as to how we might design such games in the future.

The discussion in this chapter will be structured around layers and aspects of face-to-face augmented reality games as introduced in Chapter 2 and 3. It should be noted that, as it has been indicated before, these components lie on a spectrum of mixed reality environments; the findings, observations, and reflections on each aspect of the research in this thesis, therefore, will be discussed regarding to the real world, the virtual world, and the mixed reality world as presented before in Chapter 2.

To begin with, the components of multiplayer augmented reality games may be aggregated into groups and layers. As shown in Figure 2-13, this starts from the lowest level which is **actions of each player and interactions between players**. This layer considers the actions and interactions, which are the grounding of all games (Lopes and Kuhnen, 2007), and of players, which are one of the key components of the definition of games (Rogers, 2014). After that, these face-to-face actions influence each of the three higher-level and overlapped components of multiplayer augmented reality games which are **augmented reality**, **games**, **and a multi-user system.**

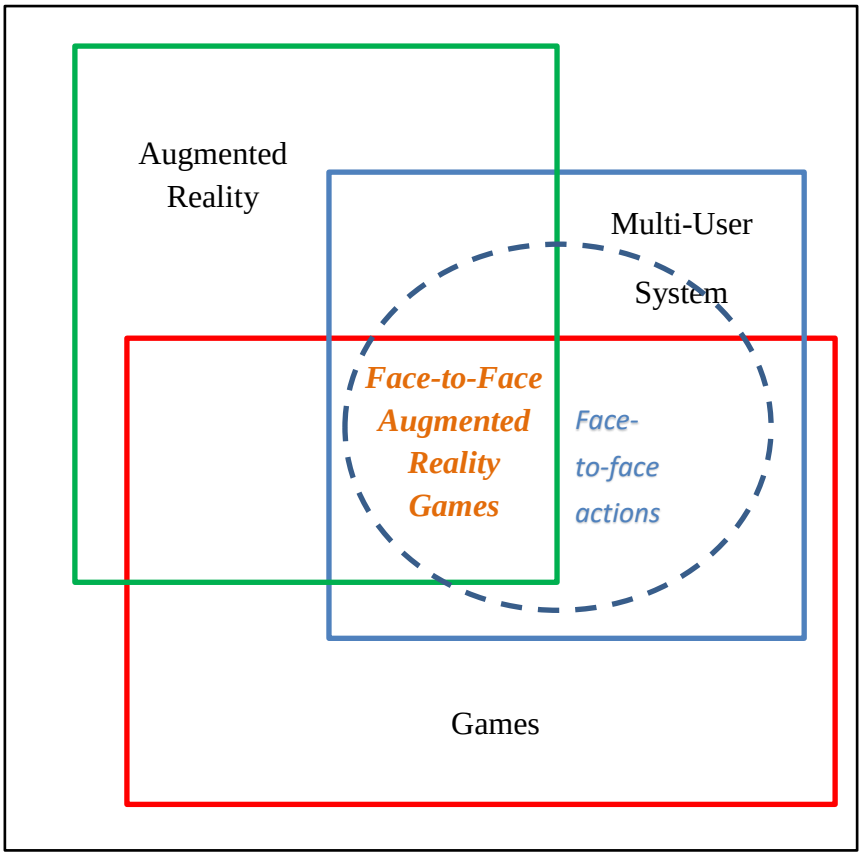


Figure 6-1 Face-to-face augmented reality games Venn diagram

By the end of this chapter, it is expected that the nature of face-to-face multiplayer augmented reality games will be more clearly defined and that guidelines of designing and developing a face-to-face multiplayer augmented reality games for future development will be established.

6.1 Face-to-face actions and interactions

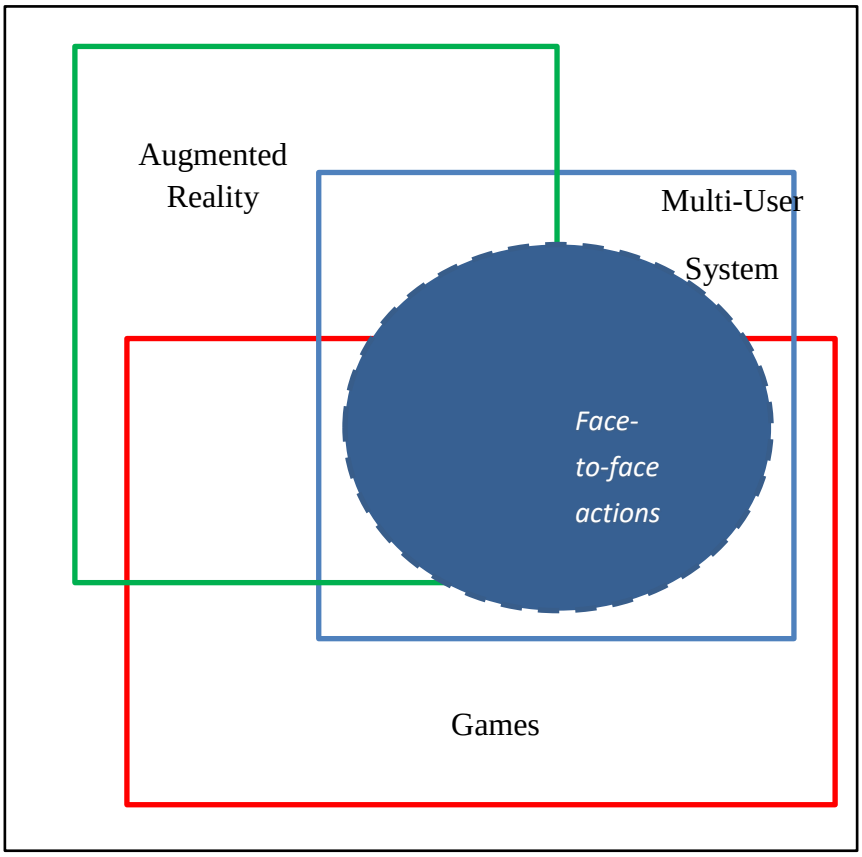


Figure 6-2 Face-to-face actions and interactions in Venn diagram

As reviewed in Chapter 2, games have structures which consist of several layers and the most bottom layer of the structure is 'verbs' which refers to the in-game actions of players (Lopes and Kuhnen, 2007). The face-to-face augmented reality game studies in this thesis concentrated on the individual actions of each player and interactions between these players. The 'actions' and 'interactions' discussed in this thesis mainly focus on physical actions that players perform in six degrees of freedom in the real world. These then generate the face-to-face actions that are the core focus of this thesis. The following discussion will, therefore, begin with the individual actions of each player, before expanding to consider interactions between players.

6.1.1 Individual actions

A physical action can be freely performed by a player in six degrees of freedom. However, as indicated in Chapter 3, a complicated-looking overall action can be considered to be a combination of thirteen basic movements on each axis: - translate left and right, translate up and down, translate in and out, roll rotations, pitch rotations, yaw rotations, and stay still. Although the actual movements are

not strictly on each axis, we can consider each of them separately. The studies in this thesis have observed how players perform and experience these movements.

The studies revealed several behaviours and opinions of study participants concerning the difficulties of each movement and the typical circumstances when these movements are performed. During the studies, participants were asked to provide the difficulty scores of each movement to help participants to compare their opinions and experiences with these individual movements. These are summarised below.

Stay still

This movement is the movement in which the user stays still for several seconds. During the studies, this type of movement is easy to learn, perform, and master. Participants reported that it is easy to perform. It is also perhaps an unusual movement in some high-energy game situations and may open up powerful opportunities for designing surprising or powerful moments of interactions.

Translate left and right

These movements are the movements in which the user translates his device horizontally. During the studies, these types of movements are generally easy to learn, perform, and master. Participants reported that they are one of the easiest movements. They can easily and successfully complete these movements by moving the device only in the range of their arms. Furthermore, they relatively rarely lose their detection from the marker while performing these movements.

Translate up and down

These movements are the movements in which the user translates his device vertically. During the studies, participants reported that these types of movements are equally easy to learn, perform, and master to move left and right. Likewise, participants can easily and successfully complete these movements by moving the device only in the range of their arms and hardly lose their detection from the marker while performing these movements.

However, there were some minor events when participants performed these movements and realised that they were at the limit of the

movement, either out of their reach when they moved upwards which caused a few users to jump or they were on the floor when they moved downwards. This did not happen frequently during the studies, but it exists.

Translate in and out

These movements are the movements in which the user translates his device in the relative distance between the players. During the studies, participants stated that these types of movements are slightly more difficult to learn, perform, and master than translating left, right, up, and down. Unlike the other position transitional movements, users sometimes require moving their whole body in order to complete the movements instead of moving the device within the range of their arms or upper body at most. This is because the range of body moving forward and backward is smaller than moving left, right, up, and down. Furthermore, users prefer to move the whole body in or out when the limitations of the body are almost reached instead of reaching the arms in or out. This is interesting since users find this approach is more convenient than moving the body hierarchically as expected in theory. However, this movement can cause a marker detection loss for a few users because they can sway the device out of the area of detection. From a design point of view, such movements may provide opportunities to bring players close together and so establish more intimate social encounters which might provoke powerful reactions among players as discussed in the previous work on intimate (Vetere et al, 2005) and uncomfortable (Benford et al, 2012) interactions.

Roll rotations (rotate clockwise and counter clockwise)

These movements are the movements in which the user rotates his screen. The observation from the series of studies reveals that sometimes when the user performs the rotation to the point that both arms which are holding the device are twisted. When the users untangle their arms, they often lose the detection during the process.

The observation also reveals that some people tend to sway the device away from the marker while performing the rotations and lose the detection. However, some people found that these movements are easy and straightforward to perform as they found it is easy to hold the device steadily while performing the rotations. Nevertheless, both groups of people took a period of time to learn and master the movements.

When participants were asked for their opinions about the movements, the first group of people found that these movements are the most difficult set of movements for them. Whereas, the latter group found that these movements are only slightly harder to perform than position transitional movements, which are the easiest group of movements.

Yaw rotations (tilt left and right)

These movements are the movements in which the user tilts his device left and right. These movements were widely noticed as one of the most difficult sets of movements during the series of studies. Study participants spent a long period of time learning how to perform the movements. When performing the movements, they often lost their marker detection which further caused struggles with the movements.

The biggest obstacle is when the user tilts the device, the screen is also tilted and swayed out of the user's sight. This compels the user to try to lean out to be able to see the screen which could frequently cause them to unconsciously sway the device out of the position and lose the marker detection as the result.

The opinions about these movements from participants during the studies were divided into two groups. The first group agreed that these movements are the most difficult set of movements to perform with a fairly wide margin from the other movements. However, the other group of people found that although these movements are difficult, they prefer these movements over roll rotations. These people move their whole body to perform the movements instead of only tilting the device which is easier to keep the detection alive.

Pitch rotations (tilt up and down)

These movements are the movements in which the user tilts his device up and down These movements are broadly similar to the yaw rotations in both observations and difficulty. However, these pitch rotation movements could be more difficult than the yaw rotation movements in some cases. During the studies, it revealed that there is a notable physical limitation when the marker lies flat. The movement of tilting up could be awfully against the natural body movements and cause a hugely uncomfortable experience when the user performs the movements since the screen is out of the eyesight range and the whole body cannot move up enough to relieve this constraint, as shown in Figure 6-3. The opinions about these movements from participants

during the studies were divided into two groups which are like yaw rotations where there were people who stated that these pitch rotations were particularly more difficult than the other sets of movements while another group reported that roll rotations were moderately more difficult than pitch rotations.

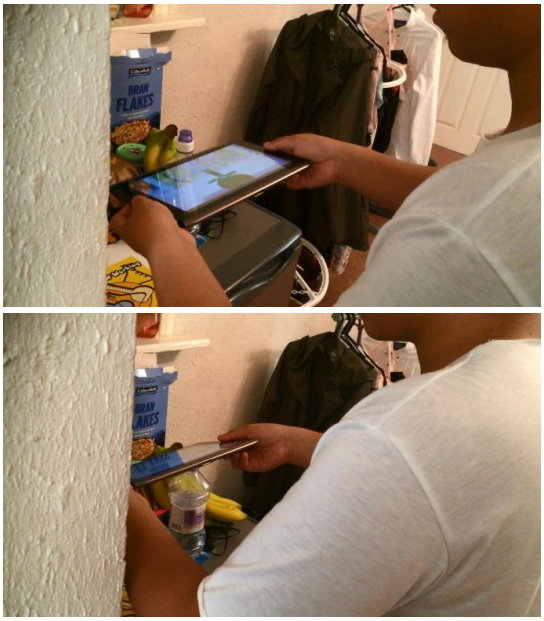


Figure 6-3 Tilting up gesture is against the natural movements

So far, these comments and observations on each movement mainly concentrate on how the movements were performed during the study and how difficult or comfortable users found them to be. However, the discussion also touched upon the issue of successful detection of the movements which we now expand upon.

In Chapter 3, a feasible area where an augmented reality application can detect a marker was raised as “detectable area” which is recapitulated below.

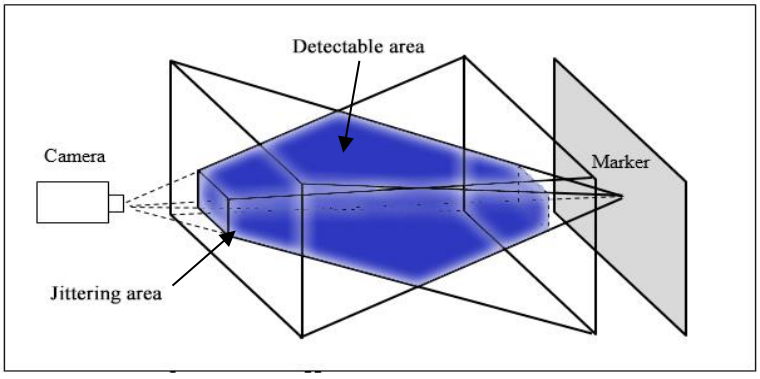


Figure 6-4 Recapitulation of augmented reality detectable area

This detectable area is created from the combination of the area of the camera view frustum and marker detection pyramid. This detectable area represents how the software senses where movements can be detected. The next stage in our reflection is to combine this with the above knowledge about which are naturally preferred by players.

According to expected, sensed, and desired interaction design framework for sensing-based interfaces (Benford et al., 2005) that was reviewed in Chapter 3, the feasibilities of various movements in an augmented reality application conspires with the physical movements and how software senses those movements. Therefore, a deeper consideration of how the body of user moves when performing each movement into consideration along with the detectable area may help shed light on the interaction design opportunities and challenges inherent in each type of movement.

The limitations of a player's movements depend on human ranges of motions. To better reflect on this, we now turn to basic knowledge of human physiology in relation to ergonomics. The human body contains several joints and muscles. When a body movement is performed, each joint will work together with the muscles to build that movement. However, each joint and muscle combination has its limitations with respect to movements, as shown in Figure 6-5.

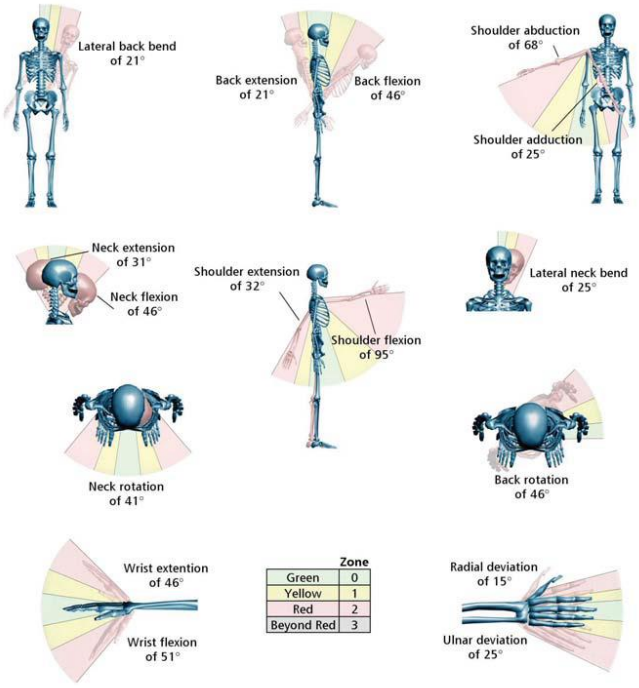


Figure 6-5 Ranges of motions of body joints (Openshaw and Taylor, 2006)

Moreover, the nearer to the point of limitations the joints and the muscles are, the more difficult the movement will be to perform. This is because the body requires more energy to move muscles that are under more tension. Therefore, a natural body posture requires the least amount of energy to perform, as shown in Figure 6-6.

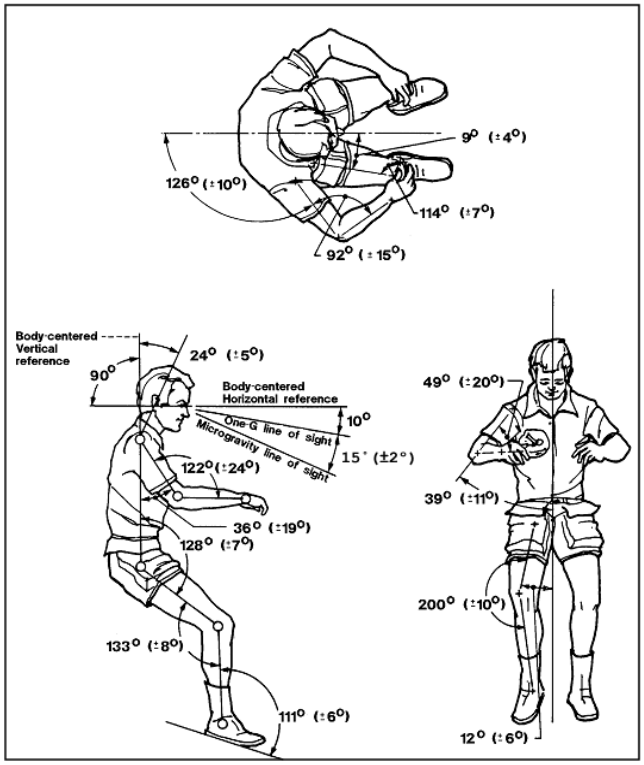


Figure 6-6 Natural body posture (Man-systems integration standards, Volume 1, 1995)

Furthermore, joints in the human body are connected hierarchically. The movement of the parent joint causes the child joint relocation as well. These hierarchies affect the actual limits of each joint movement. The hierarchies of human joints are shown in Figure 6-7.

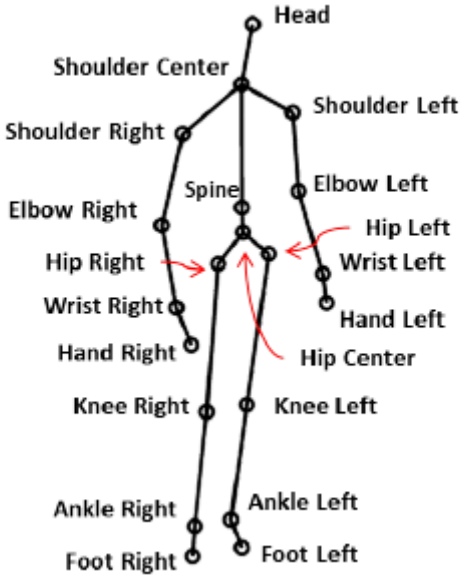


Figure 6-7 Hierarchies of human joints (Hussein et al., 2013)

Therefore, the movements of each person are limited by these human ranges of movements. Additionally, it is more difficult to perform the movement if it is opposed to the natural body posture. This includes the eyesight range presented in Figure 6-6. The most related joints to perform a movement in face-to-face augmented reality are hands, wrists, elbows, shoulders, and the head. This forms the ergonomics of physical augmented reality actions, and since each movement requires a different set and direction of muscles to perform, at least partially accounts for the difficulty of each movement, each set of movements is now considered again below to discuss the reason behind the difficulties that study participants felt when they performed each movement during the studies.

Stay still

When the user tries to complete this movement alone, this movement does not require any set of muscles. In general, the movement is within a comfortable zone of the movement. Therefore, users reported that this movement is easy to complete.

Translate left and right

The moving joints that are required in these movements are mostly shoulders and elbows without affecting the joints from the wrists downwards. When the limit of these joints is reached, the upper body

will be moved using the hips and spine. Then the whole body is possibly moved using the leg joints when the limit of upper body joint is reached.

However, when these movements are generally performed. Considering these movements from top-down and front perspectives, translating left and right movements can be completed within the range of user's arms. On the other hand, these movements do not cause any movements when considered from a side view. Although these movements are limited by the left and right edges of the augmented reality detectable area, these edges are normally wide enough for ergonomic movements. Since these movements are generally in a comfortable zone, users, therefore, commented that these movements are easy to perform and complete.

Translate up and down

The moving joints that are required in these movements are mostly shoulders and elbows without affecting the joints from the wrists downwards as moving left and right. When the limit of these joints is reached, the upper body will be moved using the hips and spine. However, when the limit of upper body joints is reached, the whole body can be moved in a moving down action to the limit of the floor but cannot be moved further in a moving up action except when the body performs a jump.

When these movements are generally performed from side and front perspectives, translating up and down movements can be completed within the range of user's arms. On the other hand, these movements do not cause any movements when considered from a top-down view. Although these movements are limited by the top and bottom edges of the augmented reality detectable area, these edges are normally wide enough for ergonomic movements. Since these movements are generally in a comfortable zone, users, therefore, commented that these movements are easy to perform and complete.

Translate in and out

The moving joints which are required in these movements are also mostly shoulders and elbows without affecting the joints from the wrists downwards, in the same manner as the previous movements. When the limit of these joints is reached, the upper body will be moved using the hips and spine. Then the whole body is possibly moved using the leg joints when the limit of the upper body joint is reached. Another physical

limitation is when the camera is moved in closer, it could collide with the marker.

When these movements are generally performed from top-down and side perspectives, translating in and out movements can be completed within the range of user's arms. On the other hand, these movements do not cause any movements when consider from a front view. These movements are limited by the front and back edges, also minimum and maximum detection distance, of the augmented reality detectable area. However, as mentioned before, users sometimes prefer moving the whole body instead of using only their arms. Since the distance the whole body can move is much greater than the arm range, it sometimes causes detection loss. This is why users still found these movements are slightly more difficult than translate left, right, up, or down although these movements are still in a comfortable zone.

Roll rotations (rotate clockwise and counter clockwise)

From a physical body perspective, the moving joints which are required in these movements are mostly all joints from the shoulders downwards. The limitations are of the range of those joints and arms.

When these movements are generally performed, there is no limitation in an augmented reality detection point of view. Considering these movements from a front perspective, roll rotations are always within detectable area. On the other hand, these movements do not cause any movements when considered from top-down and side views. However, on a physical side, there are two points where users can lose the detection. Firstly, when users rotate the device until the point where the arms are twisted, users can lose the detection when they try to untangle their arms. Secondly, when users rotate the device to the zone of an uncomfortable angle of the wrists, users will have a higher chance of reorganising their posture which could cause the camera to sway from the marker and lose the detection. This depends on how users hold the device. This divided the opinions over these movements between the two groups as stated before.

Yaw rotations (tilt left and right)

From a physical body perspective, the moving joints which are required in these movements are mostly all joints from the shoulders downwards. Furthermore, there are limitations in the eyesight range which can cause the whole body to move at the limit points of movements.

When these movements are generally performed from all perspectives, yaw rotations can easily shift out of the detectable area. On a physical side, these movements can cause the angle of wrists, arms, and eyesight out of the comfortable zone. These are the reasons behind the difficulties when users performed during the studies. However, it also depends on how users hold the device which cause a different angle of joints as some participants reported that they found roll rotations were more difficult than the other kinds of rotation.

Pitch rotations (tilt up and down)

Similar to yaw rotations, the moving joints which are required in these movements are mostly all joints from the shoulders downwards. Furthermore, there are limitations in the eyesight range which can cause the whole body to move at the limit points of movements. Pitch rotations also can easily shift out of the detectable area when considering these movements from all perspectives. On a physical side, these movements can cause the angle of wrists, arms, and eyesight out of the comfortable zone. This is why pitch rotations are as difficult as yaw rotations. It also depends on how users hold the device, which causes a different angle of joints. This also causes distinct opinions on every kind of rotations.

It is noticeable that, for some sets of movements, the actual performances during the studies contrast with the theory to some extent. For example, users prefer to move the whole body when translating in and out instead of moving the body from the utmost limbs hierarchically. One possible reason behind these, is that users may think of the device as part of their body. James Walsh from Extra Credits (2012b) proposed the name of this situation as 'Kinesthetic Projection' where humans see tools as extensions of their body when using them. For example, when driving a car, humans think that they themselves are turning along the road instead of they are turning the wheel to turn their car. Humans tend to ignore the tools they are using or holding and move their body as they found they are most comfortable as if the tools did not exist. Similarly, when users perform the movements, they see the tablet they are holding as an extension of their body. Therefore, users try to maintain their comfortable stance instead of moving hierarchically as observed.

In summary so far, all movements have various limitations from the augmented reality tracking point of view and the physical ranges of the human body movement point of view. This information is crucial for the design of face-to-face multiplayer augmented reality games as it includes the core mechanisms

that underpin a higher level of interactions and game mechanics. The summarised information is presented again in Table 6-1.

	Augmented reality tracking	Human body ranges of movement
Stay still	N/A	N/A
Left and right	Left and right edges of augmented reality detectable area	- If the joints used are the shoulders downwards (arms performance) or hips (upper body performance), the limitations are the range of motions of those joints. - If the whole body is moved, there are no limitations.
Up and down	Top and bottom edges of the augmented reality detectable area	- If the joints used are the shoulders downwards (arms performance) or hips (upper body performance), the limitations are the range of motions of those joints. - If the whole body is moved, moving up's limitation is the reaching range of the whole body plus jumping performance and moving down's limitation is the floor.
In and out	Front and back edges of the augmented reality detectable area, also minimum and maximum detection distance	- If the joints used are the shoulders downwards (arms performance) or hips (upper body

		performance), the limitations are the range of motions of those joints. - If the whole body is moved, moving in's limitation is the other player's position while moving out has no limitation.
Roll rotations	N/A	Two arms can perform the rotation until the arms twisted.
Yaw rotations	Left and right edges of the augmented reality detectable area	Range of motions of the shoulder joints downwards plus the range of eyesight
Pitch rotations	Top and bottom edges of the augmented reality detectable area	Range of motions of the shoulder joints downwards plus the range of eyesight

Table 6-1 Summarisation of components of movement limitations

6.1.2 Face-to-face interactions

Actual gameplay in face-to-face augmented reality games focuses on collaborative face-to-face interactions between two or more players. We, therefore, return to our analysis of basic movements on more time to now consider how this is affected by the presence of multiple players.

Face-to-face interactions occur when two or more people who are facing each other perform individual physical actions, which have been discussed in the previous section, at the same time. These movements are the essential part of this research. However, it is noted that the face-to-face interactions that are discussed in this thesis will concentrate only the interactions between two people.

As presented in Chapter 4, at the beginning, there are possible 169 combined movements from the interactions between the two devices as presented in a blank 13x13 table as shown below.

		Still	Transitions						Rotations					
			X (+)	X(-)	Y(+)	Y(-)	Z(+)	Z(-)	Roll (+)	Roll(-)	Yaw(+)	Yaw(-)	Pitch(+)	Pitch(-)
Still														
Transitions	X (+)													
	X(-)													
	Y(+)													
	Y(-)													
	Z(+)													
	Z(-)													
Rotations	Roll (+)													
	Roll(-)													
	Yaw(+)													
	Yaw(-)													
	Pitch(+)													
	Pitch(-)													

Table 6-2 Recapitulation of a blank table of combined movements between two devices

This table was initially filled in Chapter 4 using individual movements of each player leading to a simplified table with seven groups of relative interactions instead of the original 169 interactions, as shown in Table 6-3.

		Still	Transitions						Rotations					
			X (+)	X(-)	Y(+)	Y(-)	Z(+)	Z(-)	Roll (+)	Roll(-)	Yaw(+)	Yaw(-)	Pitch(+)	Pitch(-)
Still		X	A	A	S	S	A	A	R	R	/T\	/T\	/T\	/T\
Transitions	X (+)	A	A	X	C	C	A	A	C	C	C	C	C	C
	X(-)	A	X	A	C	C	A	A	C	C	C	C	C	C
	Y(+)	S	C	C	S	X	C	C	C	C	C	C	C	C
	Y(-)	S	C	C	X	S	C	C	C	C	C	C	C	C
	Z(+)	A	A	A	C	C	X	A	C	C	C	C	C	C
	Z(-)	A	A	A	C	C	A	X	C	C	C	C	C	C
Rotations	Roll (+)	R	C	C	C	C	C	C	R	X	C	C	C	C
	Roll(-)	R	C	C	C	C	C	C	X	R	C	C	C	C
	Yaw(+)	/T\	C	C	C	C	C	C	C	C	/T/	/T\	/T\	/T\
	Yaw(-)	/T\	C	C	C	C	C	C	C	C	/T\	/T/	/T\	/T\
	Pitch(+)	/T\	C	C	C	C	C	C	C	C	/T\	/T\	/T\	/T/
	Pitch(-)	/T\	C	C	C	C	C	C	C	C	/T\	/T\	/T/	/T\

Table 6-3 Recapitulation of all possible relative movements

X – This relative movement does not cause any changes in visual detections.

A – Devices are moving in parallel in different directions on screen. The relative movement is interpreted as the observer's device is moving in plus or minus directions.

S – Devices are moving in or out. The relative movement is interpreted as the observer's device is moving in or out of the other side.

R – Devices are rotating around the Y axis. The relative movement is interpreted as the observer's device is performing a roll rotation gesture in clockwise or counter clockwise directions.

/T/ – Devices are tilting in the same direction. Therefore, at a certain point, two devices would be in a parallel gesture, like gesture A. The relative movement is interpreted as the observer's device is moving in plus or minus directions.

/T\ – Devices are tilting in a different direction. The relative movement is interpreted as the observer's device is tilting.

C – More than one type of movements is performed at the same time. Movements are complicated and independent. The relative movement is interpreted per each individual movement.

These relative movements are produced from the movements of two individual devices which introduce some ambiguities. As these combined movements rely only on the vision from the camera and do not include any other sensors, it is possible to interpret that these movements were not necessarily intended. This situation is similar to when people sit on a bus, people sense the other people as they are staying still whereas they are moving forward at the same velocity with the bus.

These combined relative movements were improved in the studies in Chapter 5 by including data from onboard movement sensors – an accelerometer and a gyroscope. This enables the system to successfully distinguish those ambiguous combined movements and create an additional dimension to the face-to-face interactions. Game designers can implement additional game mechanics on these additional combined movements alongside the original non-movement-sensor combined movements.

However, the studies in this thesis reveal that there are still some limitations on the precision of the device's positions. Since an accelerometer recognises the acceleration and a gyroscope recognises the orientations of the device, it is difficult to obtain the global position of each device. Although positions can be obtained from the integration of the device's accelerometer, small errors can

accumulate into a larger error later on. A better approach to positioning may be to use additional sensors such as GPS for a large area or WPS for an indoors area. However, studies of using data from these sensors are not included in this thesis and so this remains a topic for further research.

Considering in terms of limitations of face-to-face interactions, these are created from the limitations of each individual action which was presented in Section 6.1.1. Those limitations of combined movements will be filled in Table 6-2. The result shows that although there are 169 combined movements in total, there are only four types of limitations that can occur, as shown in Table 6-4.

		Still	Transitions						Rotations					
			X (+)	X(-)	Y(+)	Y(-)	Z(+)	Z(-)	Roll (+)	Roll(-)	Yaw(+)	Yaw(-)	Pitch(+)	Pitch(-)
Still		X	T	T	D	D	T	T	X	X	A	A	A	A
Transitions	X (+)	T	T	X	D / T	D / T	T	T	T	T	A / T	A / T	A / T	A / T
	X(-)	T	X	T	D / T	D / T	T	T	T	T	A / T	A / T	A / T	A / T
	Y(+)	D	T	T	D	X	T	T	D	D	A / T	A / T	A / T	A / T
	Y(-)	D	T	T	X	D	T	T	D	D	A / T	A / T	A / T	A / T
	Z(+)	T	T	T	D / T	D / T	X	T	T	T	A / T	A / T	A / T	A / T
	Z(-)	T	T	T	D / T	D / T	T	X	T	T	A / T	A / T	A / T	A / T
Rotations	Roll (+)	X	T	T	D	D	T	T	X	X	A	A	A	A
	Roll(-)	X	T	T	D	D	T	T	X	X	A	A	A	A
	Yaw(+)	A	A / T	A / T	A / T	A / T	A / T	A / T	A	A	T	A	A	A
	Yaw(-)	A	A / T	A / T	A / T	A / T	A / T	A / T	A	A	A	T	A	A
	Pitch(+)	A	A / T	A / T	A / T	A / T	A / T	A / T	A	A	A	A	A	T
	Pitch(-)	A	A / T	A / T	A / T	A / T	A / T	A / T	A	A	A	A	T	A

Table 6-4 All limitations of relative movements

X – There is no default limitation in this relative movement.

T – The limitation is the leftmost, rightmost, upmost, or down most detection of the SDK.

D – The limitation is the maximum or minimum distance detection of the SDK.

A – The limitation is the critical angle detection of the SDK.

The other limitations are combined limitations, whichever exceed first.

Individual actions and face-to-face actions can be implemented into many kinds of gameplay. However, as they have different degrees of difficulties to perform,

suggestions on their application, learning process, and user experience which are concluded from the series of studies are provided as follows.

Stay still

This movement is easy to perform. However, to complete a staying still movement on face-to-face interactions might not be easy. It depends on the social scenarios which will be discussed later. The action which could be implemented over this movement is varied and easy to design since there is no boundary of movements in both physical movements and augmented reality tracking.

Moving left and right

This is undoubtedly the easiest set of movements to be performed. They are also the easiest set of movements to be implemented in a game since it is easy for a game designer to design an action in a game on these movements because it resembles many physical actions in real life and these movements are reliable because the detection area is wide. It is also easy for a game programmer to implement them to the game mechanics since these movements rely on the position of the marker.

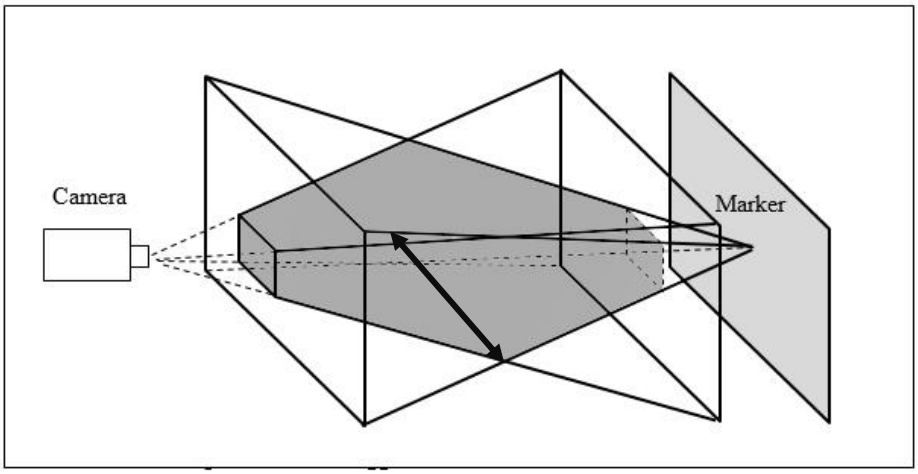


Figure 6-8 Size of gameplay space for moving left and right

These movements are performed in the best condition in a medium-size gameplay space. Although the face-to-face actions are mirrored, their face-to-face interactions are still easy to perform as the direction is mirrored. This set of movements should be one of the first movements to be included into an augmented reality game that involves face-to-face movements. Actions that could be implemented on these movements, based on all previous metaphors and game designs, are the actions that could manipulate the

virtual objects directly such as pull, loosen, stretch, etc. These movements provide a medium level experience of the reality to users.

Moving up and down

Similar to the left and right movements, this is another easiest set of movements to be performed. Although the movements are slightly more difficult than the left and right movements if the marker is not in a regular shape, they are as equally easy to be implemented to a game as left and right movements since, with the same reason as the first set of movements, it is easy for a game designer to design an action in a game on these movements because it resembles many physical actions in real life and these movements are reliable because the detection area is wide. It is also easy for a game programmer to implement them to the game mechanics since these movements rely on the position of the marker.

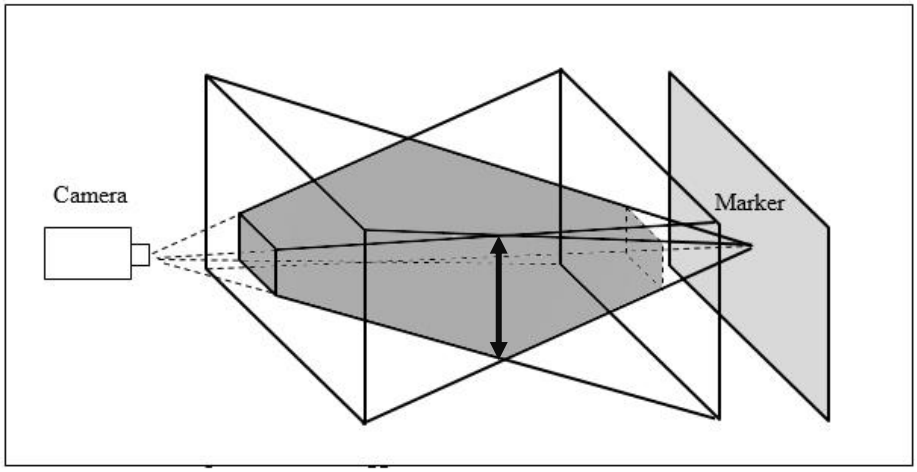


Figure 6-9 Size of gameplay space for moving up and down

These movements are performed in the best condition in a medium-size gameplay space. Unlike the left and right movements, the face-to-face actions are not mirrored, and the face-to-face interactions are easy to perform. This set of movements should be one of the first movements to be included into an augmented reality game which involves face-to-face movements. Actions that could be implemented on these movements, based on all previous metaphors and game designs, are the actions that could manipulate the virtual objects directly such as pull, loosen, stretch, etc. However, one issue to be cautious about is the height of the player when moving up. Unlike the other movements, this physical limitation could be an issue if it is not taken into consideration. These movements provide a medium level experience of the reality to users.

Moving in and out

This is another easiest set of movements to be performed. They are as equally easy to be implemented to a game as left, right, up, and down movements. It is easy for a game designer to design an action in a game on these movements because it resembles many physical actions in real life and these movements are reliable because the detection area is wide. It is also easy for a game programmer to implement them to the game mechanics since these movements rely on the position of the marker.

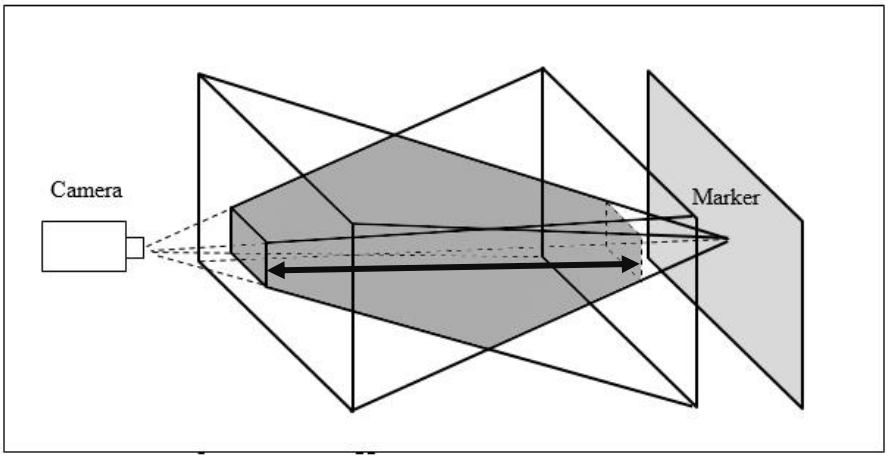


Figure 6-10 Size of gameplay space for moving in and out

The face-to-face interactions are easy to perform. However, unlike the previous movements, these movements are performed in a wide gameplay space. Moreover, these movements possibly involve the whole-body movement which could lead to a detection loss. The limitation of moving in is limited to the position of the opponent as they can collide with each other. This should be taken into consideration. Furthermore, on some augmented reality algorithms, the detection will be more unstable when the marker is further away, which could cause some disruptions on the detection and objects augmentations.

This set of movements should be one of the first movements to be included into an augmented reality game which involves face-to-face interactions. Actions that could be implemented on these movements, based on all previous metaphors and game designs, are the actions that could manipulate the virtual objects directly such as pull, push, stretch, etc. Users reported that these movements provide a high-level experience of the reality to them if some realistic feelings such as elasticity are added to the objects which they are manipulating.

Roll rotations

There are two groups of users' opinions on these movements. The first group think that these movements are difficult to perform as they find it is difficult to maintain the marker on the detection frame while rotating the whole device. In contrast, the other group of users think that the movements are moderately easy to perform.

These movements rely on the angle around the perpendicular axis of the marker. Although the movements are not as easy to perform as transitional movements, they are still easy to be implemented to a game. It is easy and straightforward for a game designer to design an action in a game on these movements and it is also easy for a game programmer to implement them to the game mechanics.

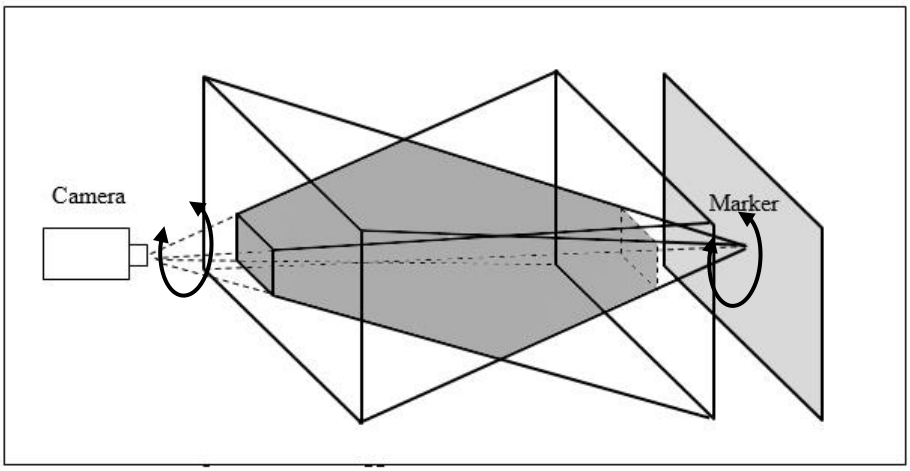


Figure 6-11 Size of gameplay space for roll rotations

These movements are performed in the best condition in a wide gameplay space. The face-to-face interactions can cause some confusion when the players ask for cooperation since the mirrored rotations are not normally seen much in daily life. The movements themselves do not contain any limitations in the software point of view. However, it is a good idea to add some manual limitations on the rotation because of two reasons. Firstly, adding some physical attributes could bring a more realistic feeling to the system. Secondly, when the user rotates his device to the point that his arms twisted, it is difficult to maintain the detection while untangling the arms creating a physical limitation. Therefore, adding a manual limitation before reaching that point will prevent this physical limitation which could interrupt the user experience from happening.

This set of movements should be the next movements to be included into an augmented reality game which involves face-to-face interactions after left,

right, up, down, in, and out movements. Actions that could be implemented on these movements, based on all previous metaphors and game designs, are the actions that could manipulate the virtual objects directly such as twist, stretch, change shape, crumble, etc. Users reported that these movements provide a high level of experience of the reality to them depending on the game context.

Yaw rotations

There are two groups of users' opinions on these movements. The first group think that these movements are extremely difficult to perform as they cannot keep the marker in the detection frame while tilting the device. On the other hand, the other group of users think that the movements are moderately difficult to perform, and it is slightly easier than the roll rotation.

These movements are difficult to be implemented to a game. Although the orientations are readable for game programmers, implementing the movements to the game mechanics also requires more information from history of detection as the detection is often lost. Likewise, a game designer needs to design an action in a game on these movements that complement the gestures while considering the fact that the detection loss happens fairly often, which is challenging and problematic.

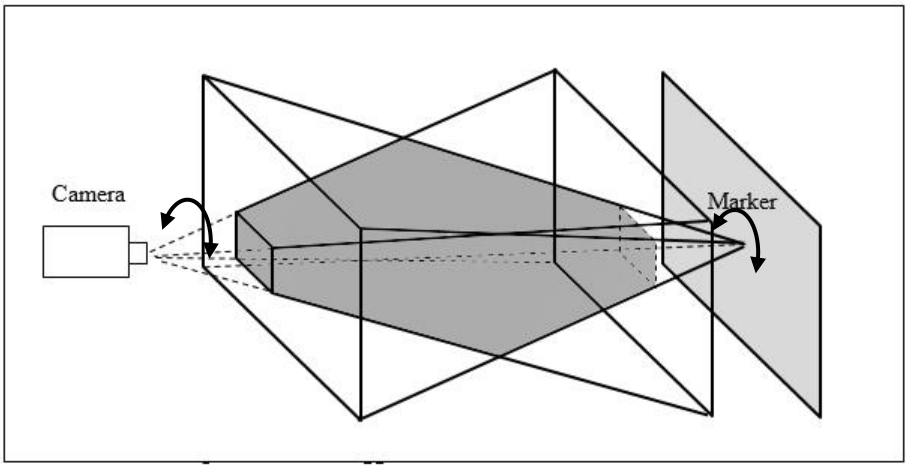


Figure 6-12 Size of gameplay space for yaw rotations

These movements are performed in the best condition in a narrow-size gameplay space. The face-to-face interactions are not confusing when the players ask for cooperation, but the difficult part is to keep the marker in the detection area. Additionally, the distance between the camera and the marker affects the angle of detection extraordinarily, which could lead to

the size of space of the interaction. Therefore, balancing all these matters is important if the movements are to be included to the game.

This set of movements should be the one of the last sets of movements to be included into an augmented reality game which involves face-to-face interactions. Actions that could be implemented on these movements, based on all previous metaphors and game designs, are the actions that could manipulate the virtual objects indirectly such as stretch, shake, blow wind, etc. Users reported that these movements provide a medium level of experience of the reality to them.

Pitch rotations

Similar to the yaw rotation, there are two groups of users' opinions on these movements. One group thinks that these movements are extremely difficult to perform as they cannot keep the marker in the detection frame while tilting the device. On the other hand, the other group of users thinks that the movements are moderately difficult to perform, and it is slightly easier than roll rotation movements.

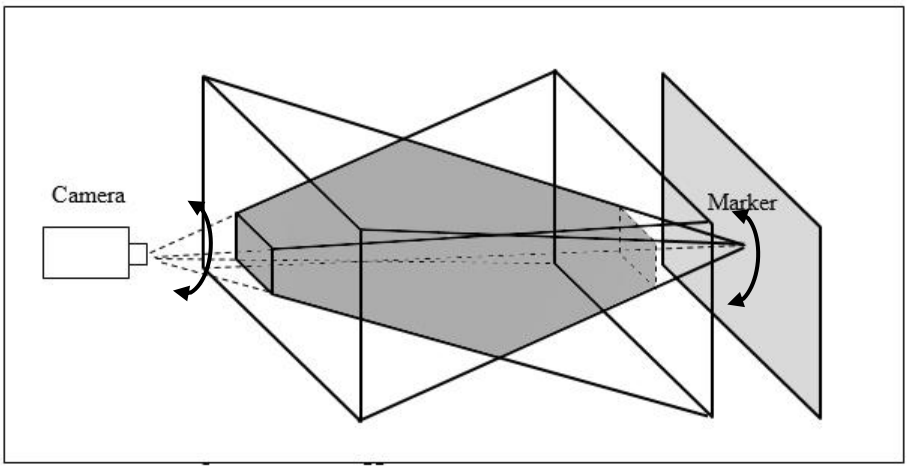


Figure 6-13 Size of gameplay space for pitch rotations

These movements are difficult to be implemented to a game with the exactly same reason as the yaw rotations. An additional issue from the yaw rotations is that the movements might be slightly harder if the marker is not in a regular shape. Furthermore, when the marker is laid flat, tilting the device up could be against the natural movement.

This set of movements should also be the one of the last sets of movements to be included into an augmented reality game which involves face-to-face interactions. Actions that could be implemented on these movements, based on all previous metaphors and game designs, are the actions that could manipulate the virtual objects indirectly such as stretch, shake, blow wind,

etc. Users reported that these movements provide a medium level of experience of the reality to them.

The information that has been discussed and learned above, which are difficulty to perform, difficulty to design and implement, size of gameplay space, and stage of gameplay that should be implemented on of each kind of movements is summarised again in Table 6-5.

	Easiness to perform	Easiness to design and implement	Size of gameplay space	Stage of gameplay that should be implemented on
Stay still	Easy	Easy	Medium	Early stage
Left and right	Easy	Easy	Medium	Early stage
Up and down	Easy	Easy	Medium	Early stage
In and out	Easy	Easy	Wide	Early stage
Roll rotations	Medium	Easy	Wide	Middle stage
Yaw rotations	Difficult	Difficult	Narrow	Last stage
Pitch rotations	Difficult	Difficult	Narrow	Last stage

Table 6-5 All movements information and suggestions

This concludes the basic information of face-to-face actions and interactions which will be the foundation of the rest of this discussion chapter and will be discussed along with other three higher-level components of face-to-face augmented reality games in further sections.

6.2 Augmented reality

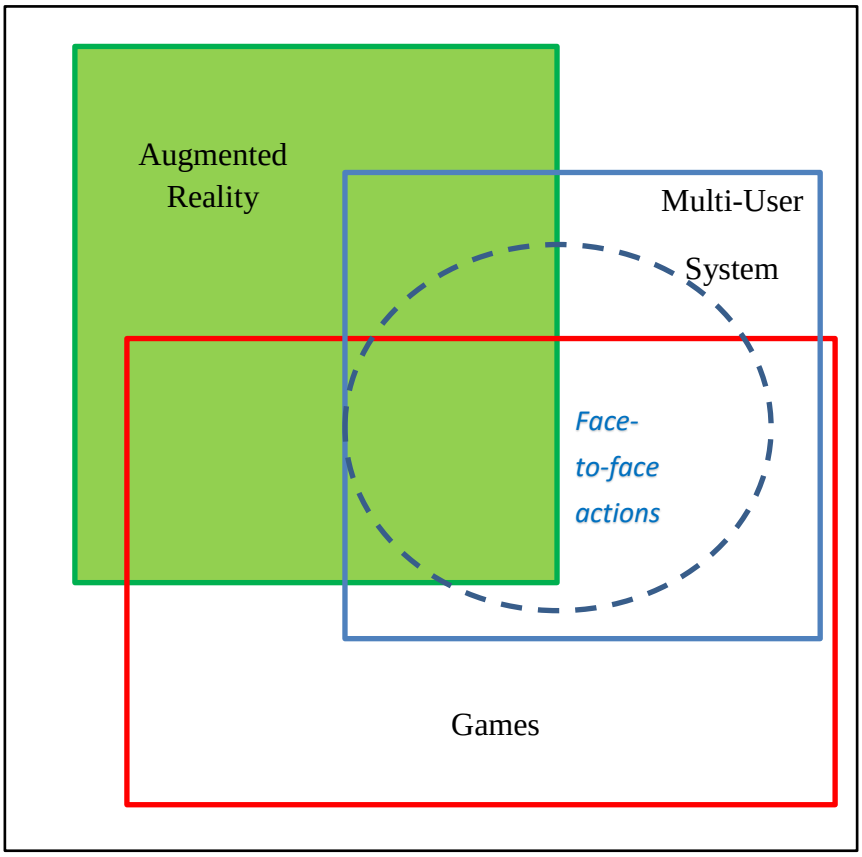


Figure 6-14 Augmented reality in Venn diagram

In the previous section, the face-to-face movements and interactions which are fundamental to face-to-face multiplayer augmented reality games were discussed from the point of view of usage, limitations, and potential applications. Moreover, suggestions on movement implementations have also been offered. In this section, these movements are going to be discussed in terms of what and how they affect the design of the augmented reality technologies that implement them. Conversely, the discussion also considers those elements of an augmented reality system that may further affect the movements and how they do so.

In Chapter 2, the augmented reality basic architecture structure (Macwilliams et al., 2004) was reviewed, revealing six main subsystems of generic augmented reality: Interaction, Tracking, Context, Presentation, World Model, and Application. These subsystems serve different purposes within an augmented reality system, as recapitulated in Figure 6-15 below.

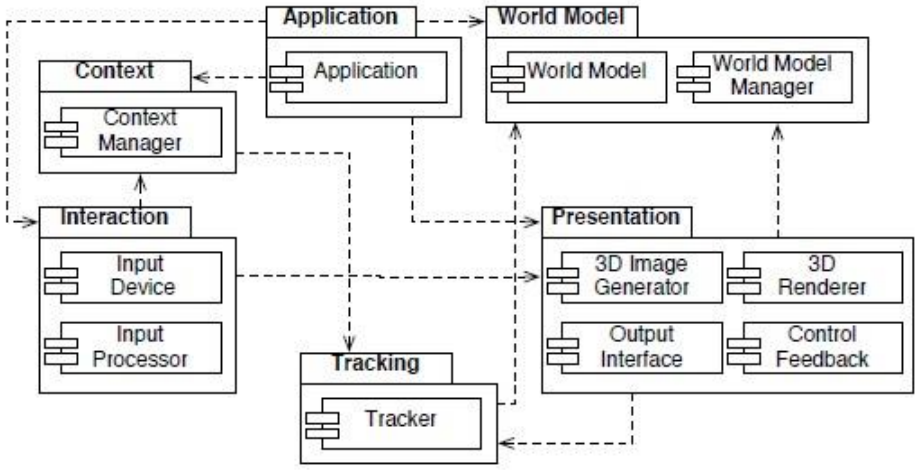


Figure 6-15 Recapitulation of generic augmented reality system reference architecture (Macwilliams et al., 2004)

Considering these subsystems, they show the overall flow of an augmented reality system. To simplify the flow, they consist of three main parts: inputs, process, and outputs. In this section, inputs and outputs of augmented reality will be discussed while a process in face-to-face augmented reality games, which is simply the game mechanic, will be discussed later in the next section.

6.2.1 Inputs in augmented reality

Inputs in marker-based augmented reality contain tracked information from markers and extra inputs through other device input sensors such as a touchscreen, accelerometer, gyroscope and GPS. It is noted that in this particular face-to-face augmented reality game realisation, markers are attached to the back of the tablet to track physical movements of other players.

Markers

One key component which is tracked in a face-to-face augmented reality system is the markers on the backs of the tablets. The design of these markers introduces several factors which could affect the movements, face-to-face actions and user experience. These factors will be presented below to maximise the user experience of a face-to-face augmented reality system.

Shape of the marker

Although in the past, the marker in the first set of popular augmented reality engines such as ARToolkit (Kato et al., 2000) or ARTag (Fiala, 2005) had to be in a rectangle shape with big black borders as shown in Figure 6-16 because of the detection algorithm. This is no longer necessary as the current detection algorithm has been improved and changed through years.

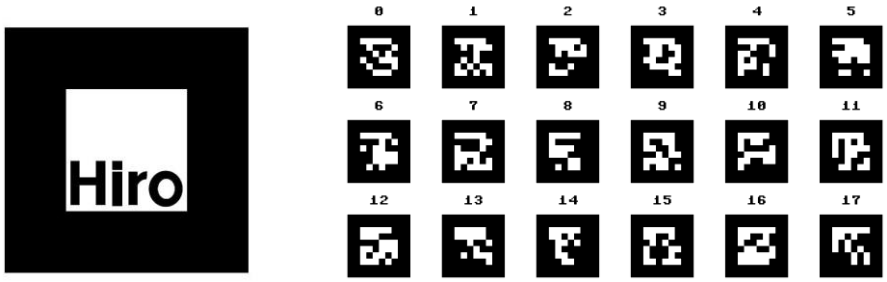


Figure 6-16 (Left) Default markers of ARToolkit (Kato et al., 2000) (Right) Default markers of ARTag (Fiala, 2005)

Currently, the shape of the marker can be varied as long as the pattern on the marker can be detected and interpretable in the system. Wormell, Foxlin and Katzman (2007) developed an augmented reality system using a circle-shape pattern as the markers. In Vuforia, any shapes of the marker can be detected and interpreted but most of the example patterns are in universal paper size ratio (1:1.4142) for convenience and simple usage and implementation. However, as face-to-face augmented reality uses player's movements as a primary input to the system, the observation from the studies suggests that the shape of the marker should be in a regular shape – square, circle, etc. This is because a regular-shape marker would give evenly good experience on each gesture no matter which direction the gesture goes.

However, there has not been any study to suggest the best shape for detection algorithm yet.

Size of the marker

There is no specific range of a suitable size for markers. Normally, the marker in an augmented reality system can be from a size of a card to the larger size of ten metres (kamoc, 2015), as long as the marker can be detected properly. However, the size of the marker can imply the space of gameplay. The ten-metre marker was created and expected to augment a fifty-metre virtual object on it which must be viewed from a hundred-metre

attitude. Therefore, the larger the size of marker is, the larger the space of gameplay will be.

In face-to-face augmented reality, a suitable size of space of gameplay is the size in which users can comfortably interact with each other. Furthermore, as a marker will be attached to the back of the device to be detected and interpreted as a gesture, the size of this marker should not be larger than the size of the marker in which the hands of the player could obstruct the detection and should be large enough to cover the device camera. As the observation from the studies showed that the ways the users hold the device are varied, the marker then should be cleared from the user's hand to avoid the obstruction from those hands. Especially, the important part of the pattern should not be placed on the areas where most people's hands are usually placed. As observed from the studies, the areas that the hands are usually placed are shown in Figure 6-17.

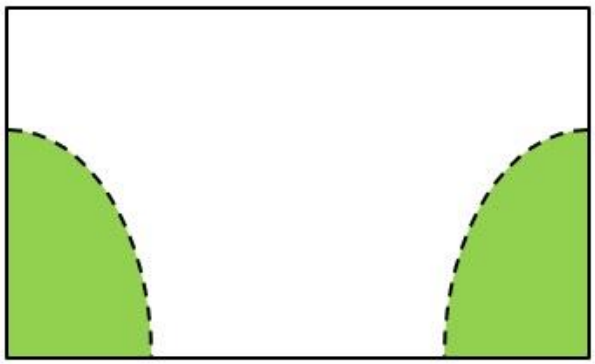


Figure 6-17 The area at the back of tablet where the hands are usually placed when the tablet is held

Position of the marker and camera

There was an interesting occurrence during the studies where two players tried to perform an interaction within a very short range. The detection was lost although the players felt they were in the position that the detection could be completed. This is because the position of the marker and camera was not in a straight line of sight. Many devices are also varied in terms of their camera position. In the studies, the camera is on the left side of the screen which causes the detection loss when they move closer to each other even though the positions of devices are directly facing each other as shown in Figure 6-18. Players needed to move the camera right to face the marker position, which creates an inconsistent feeling to their experience.

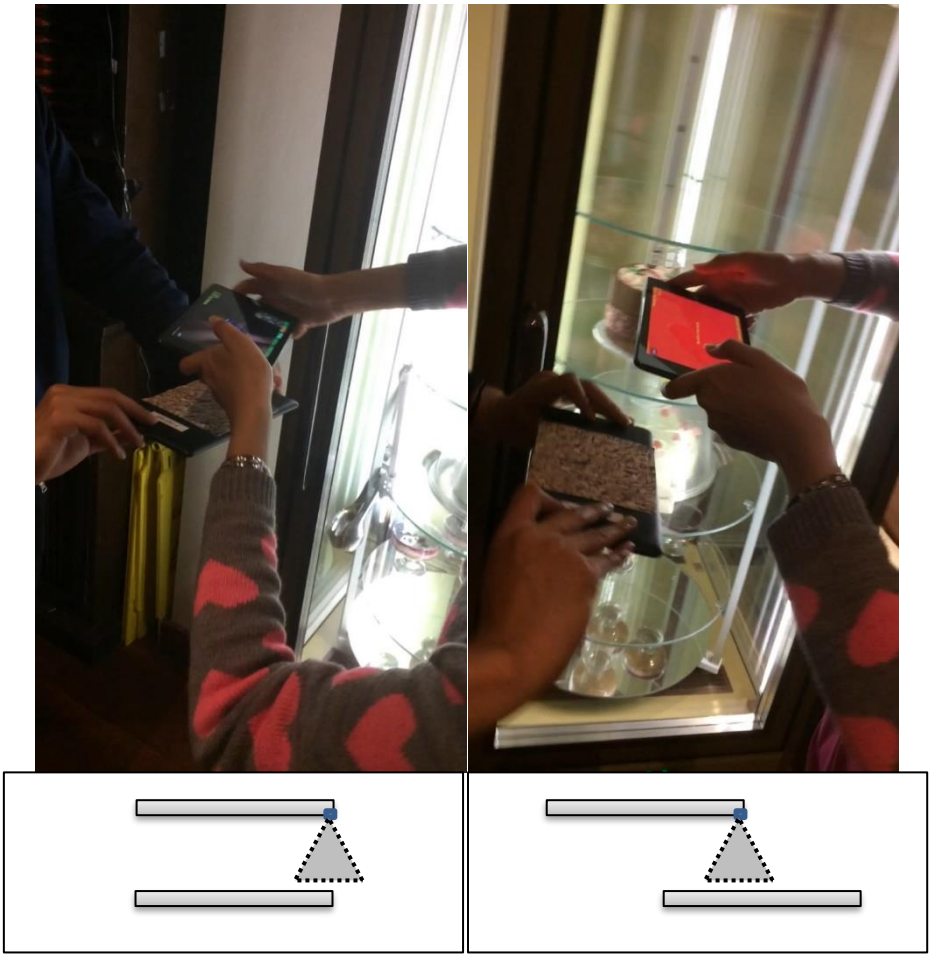


Figure 6-18 Detection lost when two devices move close to each other and the positions needed to be adjusted

Therefore, a system designer should be aware of this possibility when designing an augmented reality system and beware of the marker position which is associated with the camera position.

Pattern of the marker

As mentioned before, the detection algorithm of augmented reality technology has been improved and changed. The marker is not required to be bordered by a big black box anymore. Nowadays, the pattern can derive from any images. However, the pattern of the marker should be clear and detectable.

The marker pattern should also reflect the context and content of the game setting. This is a suggestion from the series of studies that could dramatically improve the user experience. In the initial studies, the markers that were used were simple patterns of Vuforia engine. Users reported that they did

not understand the purpose of each marker. However, when the patterns of markers were redesigned, users easily understood the context and, furthermore, accepted the marker as part of the game. Since the marker is part of a mixed reality system which should be compromised in both virtual and real spaces, the user experience is noticeably declined when the marker does not reflect the objects in the virtual world. The marker could also be used to suggest the player's movement as it is also part of the virtual world. For example, markers used in the studies were designed to suggest the purpose of the marker without requiring many tutorials.



Figure 6-19 Examples of marker which are designed to be part of physical world

It is also a clever idea if a dynamic pattern can be implemented so the pattern can be changed according to the game situations. There are some attempts on producing the second screen at the back of the tablet or laptop which results in a few commercial prototypes (Mobilegeeks.de, 2014). However, these are still a concept which has not been used in practical works.

Finally, in a development term, using the same pattern of the marker in distinct colours can cause confusion during detection on some augmented reality detection algorithms. This is another observation during the study development process. The developer often does not know the detection algorithm behind the augmented reality engine. Therefore, the design of multiple markers in the same pattern with only colour alteration should be avoided.

Other inputs

In face-to-face augmented reality games where the primary input is tracked positions and orientations of the marker which moved along with physical actions, it still is possible to combine other inputs from device sensors to be cooperated with the information from the marker. There were examples from the studies where information from the accelerometer and gyroscope are considered along with the marker to distinguish the ambiguous interactions.

However, there are many more kinds of inputs to be considered, which could benefit the overall system. The discussion in this section will focus only the inputs in handheld devices such as mobile phones, tablets, etc.

Touchscreen

For handheld devices in the present, a touchscreen is one of primary inputs. Users are familiar with this kind of inputs when holding the device such as tablets or mobile phones more than physical actions. As it was noticeable during the studies, there were a few participants who unconsciously touched the tablet screen to interact with virtual objects instead of performing the physical movements.

However, it is possible to combine a touchscreen with physical actions in face-to-face augmented reality games. For example, apart from pressing buttons, a touching screen can be used as choosing or holding something which are attached to the screen. Nevertheless, how a player normally holds the device is to be considered when the mechanics of this combination is designed. Moving hands out of their position to touch the screen can cause a discrete feeling and uncomfortable experience to users. If possible, the touching area should be where thumbs or index fingers can comfortably reach without moving the whole hand.

Accelerometer and gyroscope

An accelerometer and a gyroscope are movement sensors which many devices included in their specifications. Although they are not standard sensors which every device must include, they are widely accepted as primary sensors. An accelerometer measures acceleration of the device in each axis and a gyroscope measures orientation of the device. These sensors have been integrated to face-to-face augmented reality games before in the studies in Chapter 5. They can distinguish the ambiguous face-to-face interactions with the direction that device is moving to. However, they cannot be used to accurately determine the position and distance. This is because these sensors can contain minor errors which could be cumulated over time.

GPS and WPS

GPS and WPS are sensors which could determine the position of the device. GPS measures the global position of the device which receives the data from satellite. GPS or Global Positioning System can determine the position anywhere in the world, but they still confine the accuracy only around five meters (van Diggelen and Enge, 2015). Moreover, GPS also cannot be used accurately in blocked space such as indoors, underground, near buildings, etc. (Gps.gov, 2017). On the other hand, the WPS or Wi-Fi Positioning

System uses intensity of a received signal from wireless access points with collected GPS data to determine the current position of the device (Youssef, Agrawala and Shankar, 2003). WPS can be used when the position from GPS is not accurate with blockage surroundings.

These two sensors can be used together to measure the current position of the device. They can be used along with an accelerometer and a gyroscope for more accuracy on device's position and direction calculation.

There are still various more sensors which included within devices nowadays. For example, a digital compass, an ambient light sensor, etc. These sensors could be used with visionary data from a camera to benefit a face-to-face augmented reality game system. Some more input ideas that could be corresponding with an augmented reality system have been proposed such as voice (Ganapathy, 2013). However, they will not be discussed further in this thesis.

6.2.2 Outputs in augmented reality

Augmented reality outputs can be in many forms. Primary outputs of augmented reality are undoubtedly images on screen. However, there are also other minor outputs which can bring better experience to users. This will be the discussion within this section.

Images

As mentioned above, images on screen is a primary output of an augmented reality system. Images on screen can be divided into two main groups, objects that are augmented directly to the reference points from input information and user interfaces which are normally not augmented to the screen according to the marker's pose.

Objects that are augmented to augmented reality reference points are representatives of virtual elements in the virtual world that are overlaid to reality. They can be either in 2D or 3D. Olsson et al. (2011) studied the expectations of augmented reality image outputs and found that user expects **accuracy, timeliness, and robustness** of the overlaid information. These three factors are the core concerns of augmented reality overlaid images which will be expanded below.

Accuracy

Accuracy in augmented reality is the correctness of the information a user receives. This includes the correct position, orientations, and correct feedback according to user's inputs. If these components are disregarded, the level of user experience is dramatically dropped as it was shown during the studies.

There are also points where the detection is lost. Since movements in face-to-face augmented reality can cause detection loss in various levels of possibility, an augmented reality system should contain some rules which could relieve the rendering problems when the detection is lost. During the series of studies, there were a couple of times when the objects were not shown properly, and the participants reported that these disrupted their gameplay experience.

Timeliness

Apart from accuracy of the information, the correctness of time and low latencies of image feedback are another concern which directly affects user experience. In a pilot study in Chapter 4, user experience declined because the response was not quick enough due to the hardware limitations and the efficiency of detection algorithm.

This timeliness concern relies on numerous factors along the augmented reality pipeline e.g. detection algorithm, device performance, camera quality, environments, etc. Some factors can be controlled, optimised, and improved. However, there are also some factors which are out of control. An augmented reality system should be designed and developed to work around the uncontrollable issues if possible.

Robustness

Robustness of the overlaid images does not mean the realistic sensation or quality of the virtual objects. Objects that are overlaid on the screen should reflect well with game context and the pattern of the marker. It is not necessary that the objects must be realistic if the objects are unified with the context of the game and the marker in the real world which is also part of the augmented reality system. Robustness also includes consistency of the objects. Users will believe that objects will not disappear or jitter with their approaches to the marker.

Another point of robustness is the control feedback of user's inputs, especially in face-to-face augmented reality games where inputs are primary physical movements and face-to-face interactions. By adding some reasonable attributes to the response, the gameplay experience is enhanced dramatically. For example, in the metaphor of augmented reality

interactions in Chapter 3 where solid strings being attached to a cube, it is reported that the reception is not as decent as in the metaphor that adds elastic and tangle-able attributes to the strings and these attributes respond to the gestures as if they were in the real world.

On the other hand, user interfaces are also part of the screen. Although the images are not augmented directly to the reference point, it still affects user experience. During the studies, it was found that putting guideline interface of movements on screen produces better experience than just giving a plain order of movements. It is because movements are performed in the real world. They could be unstable and unimaginable for their virtual reflection. Putting guideline interface on screen gives confidence to users to perform the gestures. They can focus on the tasks the game given instead of being worried about how to perform the movements themselves. User interfaces can also deliver current game information to user such as timer, score, etc. which are vital information in games.

Ganapathy (2013) gave a guideline for user interface in an augmented reality system as clear textual, good contrast, good grouping of information, good placement, reasonable attention sensibility, good interaction methods, distinct design of information, and good visibilities. This guideline was recursively used during the studies where user interfaces were improved. For example, user interfaces that were used in studies in Chapter 5 give information of restriction of movements. Initially, this information is placed at the bottom-right of the screen. Users reported that they barely noticed the information because they kept focusing in the middle of the screen where the movements were being executed. In a later version of the application, this restriction information was designed to appear in the middle of the screen for a few seconds before being moved to the bottom-right of the screen to gain higher attention from users. Users reported that they noticed this information more than in the former version.

Other outputs

Apart from image outputs which are a primary output of augmented reality, there are also many kinds of outputs that can be integrated to an augmented reality system. Examples of these outputs are audio, haptic feedback, etc. Henrysson, Billinghurst and Ollila (2005) studied these feedbacks with a face-to-face setup and found that audio and haptic feedback can improve user experience in an augmented reality system. By integrating one of these feedbacks to the system along with visual outputs, users reported that the system

is easier to use and more enjoyable. With all feedbacks being put together, the scores from users were the highest.

However, like images, users also expect accuracy, timeliness, and robustness from these feedbacks. Although these feedbacks might not be as simple to notice as images, these concerns are still valid for them. During the studies in Chapter 4 and 5, there were no clear observations on these additional feedbacks. However, haptic feedback was included to the system in the studies which helped study participants to indicate whether the physical movements were completed or not, which they commented that it was a helpful feature.

6.3 Games

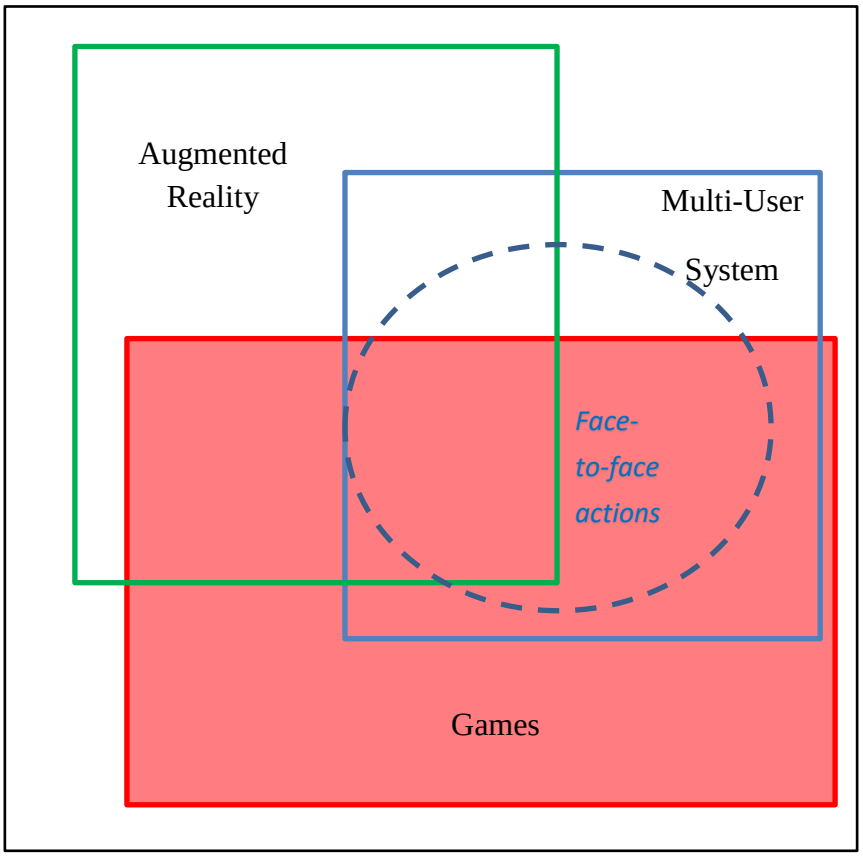


Figure 6-20 Games in Venn diagram

Of course, another key component in the concept of face-to-face augmented reality games is the game itself. Game mechanics which is implemented over the augmented reality flow adds meaningfulness to the whole system. In Chapter 2, relevant work on games as a layered view structure of the game design cognitive process (Lopes and Kuhnen, 2007) with verbs as the lowest layer and concept is the highest layer was reviewed.

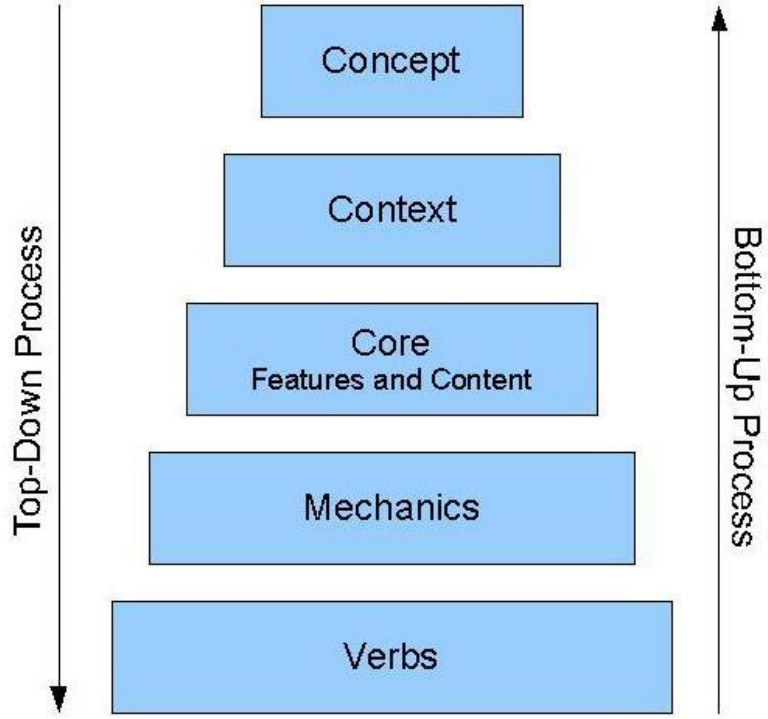


Figure 6-21 Recapulation of layered view of the game design cognitive process (Lopes and Kuhnen, 2007)

At this current state, as the face-to-face augmented reality games have been reviewed, studied, and discussed to this point, it is apparent that 'Verbs' are face-to-face actions and interactions and 'Mechanics' is the game mechanics which is integrated upon an augmented reality process. These will be the topics that are discussed in this section. Furthermore, 'Features and Content' will be concisely discussed at the end of this section.

6.3.1 Verbs in face-to-face augmented reality games

As reviewed in Chapter 2, verbs consist of a single action that the player can perform during the game. In a general game, this is the layer where actions in the game are mapped against the physical actions of the player. For example, pressing d-pads on a gamepad to move a character in desired directions or clicking the left mouse button to fire a bullet. In face-to-face augmented reality games, physical actions are the mostly the movements in six degrees of freedom as considered in detail above.

There is also ergonomics on mapping actions to verbs, physically and mentally. In 2D side-scrolling platformer games, it is widely accepted that an "A" button on a gamepad or the button which is the nearest to the right thumb will be mapped to make a character jumps. This is because 'jump' is one of the most

important actions in 2D side-scrolling platformer games. Therefore, a player requires to use the button which they can press frequently and comfortably. This is part of the physical ergonomics. On the other hand, this mapping has widely been used since the 8-bit game era. Players may recognise an awkward feeling if the jump button is changed. This is the mental ergonomics.

These also apply to face-to-face augmented reality games. Since the primary inputs of the game are physical movements in six degrees of freedom, the mapped verbs should imitate the real-world actions. For example, the studies in Chapter 4 mapped all rotating movements with actions which loosen the items from the handler, a moving out movement with a pulling action, and tilting down with a pouring action. These all resemble the real-world actions which require less time to learn and perform effectively.

However, there are still some concerns on mapping movements with real-world actions. Aesthetically, there is a hypothesis where the familiarity of human to a human replica rises according to its human likeness. However, when this replica appears almost like a real human, but not exactly, it will create an uncomfortably feeling. This is called 'Uncanny valley' (Mori, MacDorman and Kageki, 2012). The graph in Figure 6-22 shows the uncanny valley of several human-replica objects and how the feeling can change from one to another point such as a feeling where human scares of a sudden-death corpse.

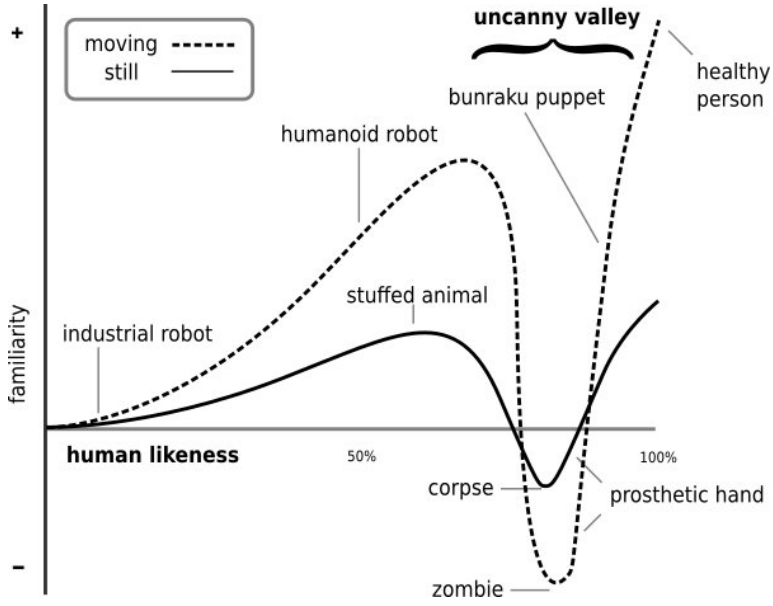


Figure 6-22 Uncanny valley emotional graph (Mori, MacDorman and Kageki, 2012)

The concept of uncanny valley applies in various fields of knowledge, including computer games. The uncanny valley can also expand into the controlling actions and methods in computer games where the controls in video games resemble real-life actions (Extra Credits, 2012b). For example, using a Wii

controller to draw a shape which requires precision such as a circle or a square is more difficult than swinging the controller to play a tennis game (Schlömer et al., 2008). Players feel tension when performing a delicate task with a controller which is not as precise as their hands.

During the pilot study in Chapter 4, initially users reported that they feel uneasy and uncomfortable when they perform the action "pour solution" which requires them to tilt down the screen. They also reported the uncomfortable feelings with other actions, but they stated that the feelings are less than the first one. After reducing the amount of degree that they are required to perform to complete the task, they reported that the uncomfortable feelings vanished, and they had fun to perform these real-world-like tasks.

The circumstance in the pilot test suggested that the uncomfortable feeling of uncanny valley can be reduced by reducing the amount of movement. This is similar to when users found that playing tennis using a Wii controller which requires less amount of movement is easier than drawing a circle.

Verbs in face-to-face augmented reality games which have been suggested before in Section 6.1.2 resemble physical-world actions e.g. pushing, pulling, shaking, twisting, bending, etc.

6.3.2 From verbs to mechanics

Mechanics is the higher layer upon verbs in a layered view of the game design which converts verbs into playable rules in games. In fact, implementing game mechanics on a verb is limitless. However, implementing meaningful game mechanics is different.

Originally, researchers understand that games should be fun. However, Hunicke, LeBlanc and Zube (2004) proposed an MDA framework to formalise the game components. They established three parts in their framework which are 'Mechanics', 'Dynamics', and 'Aesthetics'. Mechanics is the components of the game which is at the level of algorithms. The mechanics goes through the player behaviours and decisions in Dynamics and translates them into desirable emotions to the player in Aesthetics.

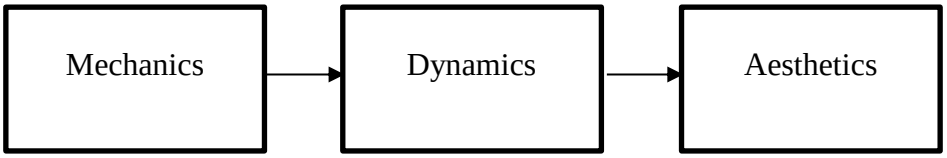


Figure 6-23 MDA framework (Hunicke, LeBlanc and Zubek, 2004)

Hunicke, LeBlanc, and Zubek suggested that instead of describing a game to one ultimate word as 'fun', the emotion that the game creates should be described in more detail. They listed a set of example emotions for games: Sensation, Fantasy, Narrative, Challenge, Fellowship, Discovery, Expression, and Submission. There are still many more aesthetic aspects of games for designers to design their games towards to. In augmented reality games, the emotions expected from the game could be any of these emotions. Since augmented reality's essential goal is to generate virtual objects that are virtually indistinguishable from the real environment (Azuma, 1997), one of the emotions that should always be included to the game is the sense of realism. In other words, it can be described that an augmented reality requires 'Fantasy' to make the player believe that the virtual objects are part of the real world to bring 'Sensation' to pleasure the sense of the player. This should always be taken into consideration when designing an augmented reality game apart from the emotions which are unique to the design concept of the game.

Olsson et al. (2011) studied the characteristics of expected user experience of augmented reality, especially in mobile augmented reality, and summarised a list of expected aesthetics of augmented reality which could be a fundamental knowledge for designing an augmented reality system as below.

Aesthetics	Description
Captivation	Feeling of being immersed and captivated in the interaction with the augmented environment
Collectivity	Sense of community, participation and belongingness by collectively creating and sharing content in the service
Connectedness	Feeling of being connected with and aware of other people using the service; having new ways of social interaction
Creativity	Creative, self-expressive and artistic feelings in creating new content and in mixing the digital with the real world
Efficiency and accomplishment	Sense of more efficient and convenient performance of everyday tasks by saving time and effort and by easing information acquisition
Empowerment	Feeling of being able to reach goals with new means that augment one's capabilities and make possible novel activities and information
Increased awareness and knowledge	Increased insight into objects, places and immediately noteworthy events in one's surroundings, as well as into one's own prior behaviour
Inspiration	Feeling of being encouraged, excited and eager to try new things or appropriate the service for new purposes
Intuitiveness	Feeling of naturalness and human-likeness in interacting with the AR information and how AR is superimposed on the real world

Liveliness	Feeling of constantly acquiring new and updated content that is socially constructed, thus making the service feel vivid and dynamic
Playfulness and entertainment	Feelings of joy, amusement and playfulness that arise from intriguing and rich content
Surprise	Receiving extraordinary and pleasurably surprising information automatically or feeling of expectations being surpassed

Table 6-6 Summarisation of expected user experience of augmented reality (Olsson et al., 2011)

The MDA framework suggests that designing a rule in game mechanics should concern that after it is combined with input behaviours from the player, the game should provide the desirable emotions to the player. Nonetheless, from the development process and study, the observation further suggested that face-to-face movements and interactions could be implemented to enhance a lot of emotions apart from what the augmented reality properties do. For example, implementing physical face-to-face interaction inputs to manipulate a virtual object instead of just leaving the virtual object augmentation on the marker tracking could further enhance the experience. For example, when players are moving out from each other, this interaction can create a 'pull' game mechanic in the face-to-face augmented reality game. However, if the object which players are pulling is a normal string such as in a tug of war game, the experience will be ruined because the players cannot feel the tension in the string like the real rope. However, if the game rule is established that the player must reach to the point behind him before the opponent without losing the detection and there is an elastic string between them, it is possible for the game to create a pleasure feeling by making the losing device vibrate to simulate the tension of a snapping string when one player reaches the goal point.

Adding reasonable control feedback from the augmented reality inputs from the player to the game will provide a 'Sensation' feeling to the players. From the studies, it was reported from participants that a small vibration when the marker detection was lost provided a better feeling for them than when nothing happened. They also reported that they somehow had pleasure when the augmented virtual object responded back as they expected when they tried to manipulate the objects.

The interactions between the players also give 'Challenge' to complete the given tasks, overcome the difficult movements, and satisfy both players' objectives in face-to-face interactions. To overcome these challenges, sometimes both players require to work together. This gives 'Fellowship' to both players by using body signals or communicating with conversations. These should be the basis of creating a game mechanics over a set of movements and interactions.

Apart from consideration about applying a movement or a face-to-face interaction to a proper game mechanics, the main concerns of those movements, which discussed before, about detection loss and space of gameplay should also be considered during game mechanics design. The detection loss issue has been discussed several times in the previous sections. This is because even a small detection loss could decrease the whole game experience because the feeling is convulsed. However, the detection loss can either be relieved by some game mechanics such as implementing a game object on screen when the detection loss occurs using history information or estimated information to reduce the convulsion of the experience, or apply the detection loss into another game mechanics itself such as a game mechanics with a shown or hidden marker.

Another consideration is the space of gameplay. It is not necessary for the space of gameplay to be bound within the marker detection area. It depends on the game design where the outside of the detection area can also be included as one of the features depending on the mechanics design. However, the space of gameplay is one of factors that affect the gameplay experience. Moreover, it can cause detection loss because the whole-body movement can cause the shakiness in which the camera cannot detect the marker.

The points raised above are only the baseline for implementing physical movements and face-to-face interactions to a face-to-face augmented reality game mechanics.

6.3.3 Game environment in the core layer

The core layer consists of features and contents in games. The whole augmented reality system is in this layer and they are varied in each game. However, a face-to-face augmented reality game does not only consist of the augmented reality system, the game environment should also be taken into consideration to maximise the gameplay experience. Since an augmented reality game is in a mixed reality environment, the contents in the core layer of the face-to-face augmented reality game should not only consider the virtual objects in the game. A face-to-face augmented reality game also requires actions and movements of the player, which normally require a larger space of gameplay than typical table-top augmented reality games.

The game environment in the real world in face-to-face augmented reality consists of the marker which is part of the augmented reality system and other game environments. Suggestions of the marker were proposed in Section 6.2.1. Therefore, the setting on the other game environments is going to be suggested in this section.

The playing space and terrains are part of the real-world environment. They are not the essential part of the game. However, user experience can be increased dramatically if the virtual objects are reasonably placed in the playing space. For example, virtual objects are not irrationally collided with any real physical objects. Furthermore, setting a game in a sensible place for the game story could also enhance the game experience. For instance, in a game set in a sports centre, any real-size virtual athlete or even a real-size virtual ninja could be more sensible to appear than a real-size virtual knight or Viking. However, a mini-size virtual knight or Viking that appears on a table in the sports centre seems right for the place.

Following the playing space environment, its size and scenario should be one of the concerns of face-to-face augmented reality gameplay. As presented in Table 6-5, each movement has its range of practical movements. Therefore, varied sizes of the playing space and scenario determine which movements and interactions should be primarily used to process the game and how the rest should be used to challenge the player. For example, yaw and pitch rotations could be used in a small size of the gameplay space such as a scenario like sitting around a table, while moving in and out could be used in a large gameplay space such as a scenario like running around to find the other players. These movements can be combined if the gameplay scenarios are designed to be dynamic. For example, moving in and out movements can be used when the players are running around, and rotation movements can be performed when the player is engaged.

A lighting condition is one of the most concerns of any augmented reality games. A bad lighting condition could cause a detection problem and immensely disturb the flow of gameplay, especially in a face-to-face situation where one player can detect the marker of the other player and that player cannot detect the marker back. This will lead to one-side success detection and this is not reasonable for the game. An ideal lighting condition is difficult to set. However, a lighting condition can also be designed to be a feature of the game. For example, a marker near the window is difficult to be detected. To do so, the player needs to move this marker away from the window while avoiding the other player to steal the detection from this marker. Overall, a lighting condition should be extremely concerned when designing a face-to-face augmented reality game.

6.4 Multiplayer

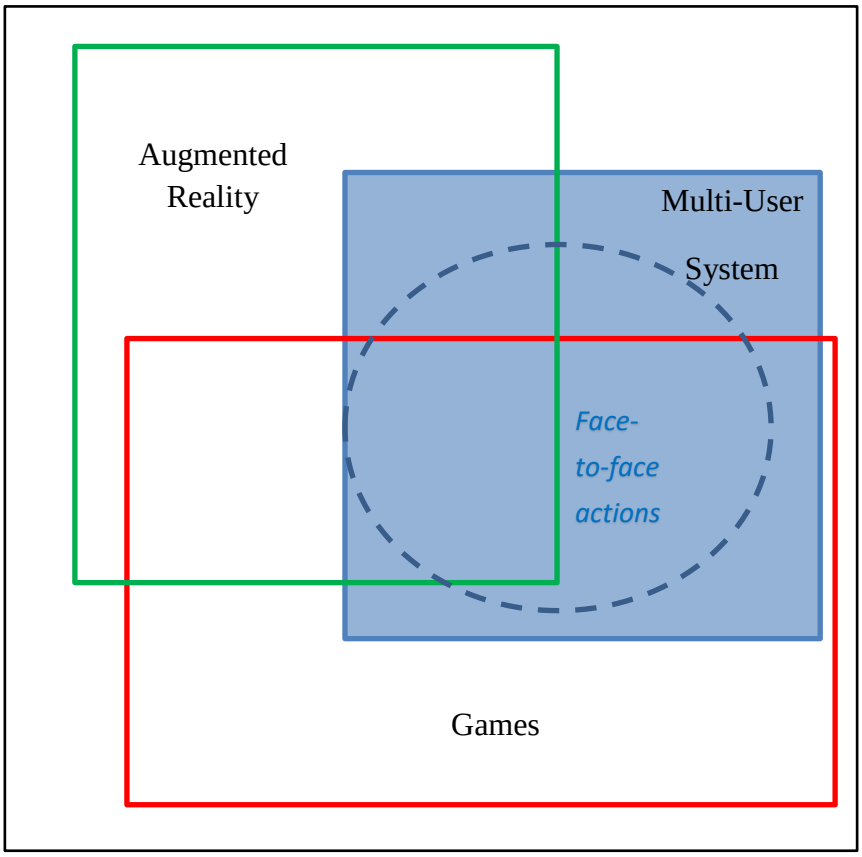


Figure 6-24 Multiplayer in Venn diagram

In the past sections, movements and interactions have been developed into an augmented reality input that has then been expanded into a game. However, there is still one last aspect of a face-to-face multiplayer augmented reality game that has not been discussed. As reviewed in Chapter 2, an augmented reality game is part of pervasive games, a form of game that expand the basic boundary of games in three different directions – spatial, temporal, and social (Montola, 2005). The main purpose of this research has already been defined in Chapter 2 and 3 that face-to-face movements and interactions are expected to expand the boundary in a social direction. Therefore, the multiplayer aspect is the final piece of the puzzle to complete the discussion of a face-to-face multiplayer augmented reality game.

Since face-to-face augmented reality involves face-to-face interactions between the marker and the camera, this creates interactions between the players if the camera is controlled by one player and the marker is controlled by the other player. The interactions are directly affected from the different social scenarios and multiplayer settings which also affect the gameplay experience. In this section, these factors in a multiplayer aspect which influence the player experience are going to be discussed.

6.4.1 Multiplayer gameplay factors

In a multiplayer setting of the face-to-face augmented reality game, there are a lot of factors which affect the gameplay and the player experience. During the studies, these factors have arisen. In this section, these issues are going to be discussed since these were addressed during the studies as the concerns of face-to-face multiplayer augmented reality gameplay.

Symmetric and asymmetric gameplay

There are two types of multiplayer games – a symmetric multiplayer game and an asymmetric multiplayer game. A symmetric multiplayer is the type of games in which all players are in the same situation and same options (Sirlin, 2014) while an asymmetric game is a game in which each player has different options or situations but they all share the same space of gameplay (Extra Credits, 2015). Some people might say that a symmetric multiplayer game is the best way to achieve a fun, fair, and balanced multiplayer gameplay (Adams, 1998). However, many games have achieved a fun and balanced multiplayer gameplay by using asymmetric gameplay approaches, which sometimes create even more fun and challenging gameplay. However, this type of games is much more difficult to design and balance (Extra Credits, 2015).

Most of the asymmetric multiplayer games give a set of different options, situations, or hide some knowledge from some users, but the common knowledge of the state of the game is visible to all players. However, in the series of studies in this research, a common knowledge feature is removed from the player's device. They do not know the other player's state unless they inform each other. This intends to maximise the significance of the movements and face-to-face interactions, as well as communications among the players, which could be a benefit to the observation of these actions. Despite this, it creates difficulties in game design and inconvenient gameplay. Nevertheless, the game is also interesting to be observed.

Because of this, to achieve a fun and balanced face-to-face multiplayer augmented reality gameplay, it is not necessary to design a game without sharing the common knowledge of the game state like the game in the study. Any form of connection between the players and between the devices could be added to a face-to-face augmented reality game such as a wireless connection, Bluetooth, etc. to create easier gameplay. This is, however, not covered in this research.

Difficulty of movements and face-to-face interactions

During the studies, the difficulties of movements and face-to-face interactions massively influence the overall gameplay. The player who receives a more difficult movement is most likely to hinder the gameplay of another player who he interacts with. These movements include moving the marker or camera away from the frame of detection such as yaw and pitch rotations. These produce unsmooth gameplay and incredibly affect the gameplay experience. However, as the skills of the player increase, this could be relieved. As it can be observed from the series of studies, many participants can perform the movements and interactions better when they are more familiar with the movements and when they are more confident. Furthermore, some social interactions such as communications among the players could also relieve this factor (Bluemink et al., 2010). This all depends on the design to achieve a good gaming experience by balancing these factors (Altimira et al., 2014). Therefore, the design should consider the difficulty level of movements as described in Section 6.1.

Nonetheless, each player has different speed on mastering the game-required skills. It might be plausible to detect and distinguish players with current skills and give them different task difficulties or even the role in team if the game is cooperating.

Communication among the players

One important issue that has been discussed frequently during the studies is that communication among the players is extremely important in the gameplay. It helps relieving any unsmooth gameplays in multiplayer games, especially face-to-face augmented reality games, and creates situations among the players. Communications also encourage the players to perform an action in the game in many social scenarios which help the game become engaging.

Communications can be performed in both verbal and body movements. This creates the space of mixed reality gameplay where the virtual world and reality are blended. However, in the setting of the game as in the series of studies, face-to-face interactions might be hindered from a body movement as a purpose of communication. This is because the body movements can affect and hinder the current movement performed to interact with the other player and cause the detection problem.

Furthermore, communications rely on the two big factors which are the intimacy between the players and the appointed social scenarios, as presented before in Chapter 2.

Intimacy between players

Intimacy between the players is a factor that a game designer cannot entirely control, but it can be appointed in the game. For example, some multiplayer games contain features in which the players can invite their friends to play together. This helps the players understand each other in the game better than when playing with a stranger.

Intimacy between the players affects the gameplay experience massively (Peng and Hsieh, 2012). During the series of studies, the group of participants which had not known each other before tended not to make many communications and performed the gestures individually. Furthermore, it seems that they tried to avoid a conflict between each other during the competitive setting by just stealing instead of blocking the other players directly like in the group of more intimate participants. However, this also depends on the personality of the players.

Appointed social scenarios

This last factor is also one of the main factors for a multiplayer game. This factor is entirely in game designer's organisation. During the studies, two contrast social scenarios were appointed, cooperative and competitive. They produced totally different gameplays although the game rules are identical. The social scenarios in face-to-face augmented reality games will be explained more in the next section.

6.4.2 Face-to-face augmented reality game in different social scenarios

As mentioned before, the social scenarios that are set in a multiplayer game tremendously influence the gameplay experience. A face-to-face augmented reality game is also included. During the studies, two different social scenarios, cooperative and competitive, which are the two bases of multiplayer activities (Deutsch, 1949) were appointed to a gameplay and the users' behaviours and their experience were observed. In this section, this observation is going to be discussed.

Cooperative gameplay

When the players were appointed to play a cooperative gameplay during the studies, most of them tried to complete the tasks individually before they realised that it was easier to work together, which required a lot of communications among them. The cooperative gameplay during the studies

seemed to create some entertaining gameplays. However, this gameplay also created confusion among players in face-to-face interactions when they tried to inform the others to help completing their movements. This is because of the mirrored gameplay in a face-to-face setting and the difficulty of the movements. In general, it was possible for the participants to cooperate with each other with a remarkable level of enjoyment.

This confirms that communications are important in cooperative gameplay (Extra Credits, 2015). People try to help each other via communications. Although the intimacy among the players are an important factor that might hinder the players to communicate with each other, this factor can be relieved by time and game design. However, these are two relationships which undoubtedly affect overall gameplay experience (Peng and Hsieh, 2012).

Competitive gameplay

In contrast with the collaborative gameplay, the players in the studies did not rely on the communications but their actions instead. Some participants tried to block the other player's actions while some participants tried to advance in their tasks silently by stealing the objects from the other players. This depends on the personality, tactics, and intimacy among the players as discussed before. Some people during studies chose to cooperate with each other and betrayed later.

Some sets of interactions are also more difficult to perform in a competitive setting. For example, in Chapter 5, staying still became one of the most frustrating movements to complete although this is one of the easiest movement in a cooperative setting.

In general, only few of study participants could complete the tasks because of a lot of detection loss. However, they reported that they felt that the game was much more enjoyable than the other settings of gameplay. This seems to be because the players feel that the competition drove them to use many more tactics than the other gameplays. Also, this gameplay can be improved by adding the features which relieve the detection loss such as a wireless connection to maintain the amusement without being ruined by the detection loss.

6.5 Conclusion

In this chapter, all previous works in this face-to-face multiplayer augmented reality game have been summarised and discussed in four main aspects: face-to-face actions, augmented reality, game, and multiplayer. Each aspect represents different main parts of a face-to-face multiplayer augmented reality

game which is layered in different levels and cannot be separated from each other.

The discussion started with the face-to-face actions which is the lowest level of a face-to-face multiplayer augmented reality game. The face-to-face actions conspire with movements that the user can perform and interactions between two players. The discussion went through the characteristics of each movement, its difficulty to perform, and the virtual and physical limitations. Two movements performed by two players produce a face-to-face interaction which also contains various traits according to the relative movements of the two players. Finally, the suggestions for implementing these movements and face-to-face interactions were presented to provide a decent initial point for the game designers and developers to start a face-to-face augmented reality game.

Face-to-face actions were brought to the discussion in higher layers. The first area is the augmented reality aspect. This aspect revealed many points and suggestions of augmented reality which are in the real world such as the marker and the virtual world such as virtual objects and their virtual feedback. This aspect gave an overall view for designers and developers in how to construct an augmented reality system on top of the defined face-to-face actions.

The discussion was shifted to another higher level which is the game aspect. Face-to-face actions and augmented reality were discussed in the point of creating verbs upon face-to-face interaction inputs and translating verbs to the main game mechanics to fulfil the desired emotions. Game environment is also discussed as one of the irrefutable factors that have an impact on face-to-face augmented reality games.

The last aspect is the multiplayer aspect. The designed face-to-face augmented reality game cannot be completed without the multiplayer discussion. The crucial factors of multiplayer interactions in face-to-face augmented reality games were observed in Chapter 4 and 5 and have been discussed here. Moreover, two contrast social scenarios which are collaborative and competitive scenarios have been discussed. These two social scenarios were included in the studies with identical gameplay and the same group of players. They caused different users' behaviours which are interesting and should be the point of concern for designers and developers for a face-to-face multiplayer augmented reality game.

In next chapter, all points of this research in a face-to-face multiplayer augmented reality game will be concluded and thought-provoking future works will be provided.

Chapter 7

Conclusion

In the past chapters, face-to-face interactions in augmented reality games studies have been examined, conducted, and evaluated in both theoretical and practical approaches. Face-to-face interactions have been observed and discussed in many depths and their applications in augmented reality games have been reflected in many aspects. It established many interesting resources for researchers and game designers who are developing a multiplayer augmented reality game with face-to-face interactions. This chapter is the last point of the studies and this thesis. It will conclude everything in this thesis and it will provide some potential future works that can emerge using the knowledge in this thesis.

7.1 Conclusion of thesis

This thesis has presented an exploration of face-to-face interactions in augmented reality games. This approach fills one of the missing gaps of the current multiplayer augmented reality games which is the interactions between players during the gameplay. The face-to-face interactions were identified as the combination of two individual movements. Each movement has thirteen possible moves in six major categories which results in 169 theoretically possible face-to-face combined movements. Each movement has its limitations in both a human body aspect such as joints of movements and an augmented reality technology aspect such as the angles and distances that the marker can be detected. This creates a space of Detectable Area when a face-to-face interaction is performed. A few initial metaphors of face-to-face augmented reality games were created, actual feelings from the face-to-face interactions were observed, and the possible game mechanics was explored. This revealed that face-to-face interactions between players have an excellent potential to be

the core game mechanics of multiplayer augmented reality games. This is, therefore, the core topic to be designed, developed, and studied in this thesis.

Currently, there is no practical existing game design process for augmented reality games. This thesis, therefore, attempted to offer a process of augmented reality game design. The process was developed by splitting "games" to many components and converted them into decks of cards. These cards can be easily drawn randomly or intentionally to create a domain of games that are being designed. When augmented reality components are included in these cards, they can be used to put a guideline on designing an augmented reality game. This designing process was tested in a series of workshops where computing veterans and gaming veterans participated. As a result, they could successfully design three multiplayer augmented reality games which include face-to-face interactions as the core mechanics even though the participants had not had much experience in augmented reality games. The designing process has not been refined any further after that series of workshops which expected a few multiplayer augmented reality games rather than a process of game design. However, this process can be a good starting point for those game designers who intend to create an augmented reality game. It can also be evaluated and improved further to become a designing framework in the future works.

Simultaneously, the game designing workshops revealed many interesting observations and concerns about multiplayer augmented reality games that required to be studied further such as technology feasibilities and social scenarios in augmented reality games which could affect the whole game experience. Games that were produced during the workshops were then re-considered and re-designed into a new single game design. After this game was successfully developed, a study of user experience and behaviours was planned based on this developed game.

The study was aimed to explore the user behaviours in face-to-face augmented reality games in various social scenarios. Participants were given tasks in an augmented reality game where they need to interact with the other participants to complete in three different social scenarios – single player, cooperative multiplayer, and competitive multiplayer. After the study, the participants gave their opinions about their experiences, difficulties, concerns, and suggestions. Everything in the study were recorded to be analysed. The study revealed several interesting points as well as revealing ambiguities in some face-to-face interactions where they could not be distinguished and created some confusion to the users. Therefore, we decided to revise the study further to remove these ambiguities and examine if there were any changes in user behaviours and their decisions.

The study was revised by including a consideration of information from on-board movement sensors which are an accelerometer and a gyroscope along

with the visual information from a camera. The game was successfully developed, and another set of studies was conducted. The studies were a simplified version of the first studies. It revealed a lot of additional observations of user behaviours which include the decisions of users and their concerns about the movements, especially staying still.

Face-to-face interactions in augmented reality games were analysed in both theoretically from the technology observation and actual gameplay from the study. It revealed that most players performed transition movements (move left, move right, move up, move down, move in, move out) without any major problems. These movements are also easy to be implemented into game mechanics. Therefore, they should be included in face-to-face augmented reality games in the first level of difficulty of the games. However, the study showed that opinions were split in the other categories of movements. Some participants reported that roll rotations were easier to perform than yaw and pitch rotations while other participants thought otherwise. Considering the implementations of the interactions to a game mechanics, size of detectable area, and scores which participants during studies gave to these movements, it suggests that roll rotations should be implemented in the middle level of difficulty of the games while the rest should be in the last level of difficulty of the games. Meanwhile, staying still is easy to implement to the game mechanics but its difficulty of performing depends on the appointed social scenario. Moreover, it is concluded that staying still, moving left, moving right, moving up, and moving down have a medium size of playable space according to their detectable area. In the same manner, moving in, moving out, rotating clockwise, and rotating counter-clockwise have a wide size of playable space while the rest have a narrow size of playable space.

Face-to-face interactions then were taken to higher levels. The first area is augmented reality. It was discussed in part of inputs and outputs of the system. On the input side, the discussion focused on markers in games which have another key role apart from being the anchor points for an augmented reality system. They can be part of the real-world game experience with their marker pattern design, size, and shape of the markers. Furthermore, it was discovered during the study that face-to-face interactions could be guided by 2D user interface that reflects the current situation of the interactions. This produces a better experience to users when they perform face-to-face interactions. Other kinds of inputs were also discussed, and they could be used along with visual information from the camera. On the output side, the discussion went through the image output which requires accuracy, timeliness, and robustness. A proper output with these three attributes gives a much richer experience to players while outputs which fail to satisfy one of these three attributes might lead to a declined user experience. Other outputs such as audio and haptic feedback were

also discussed as helpers to deliver better user experience, but they also require accuracy, timeliness, and robustness as the image output.

Face-to-face interactions and augmented reality were considered together to create the game verbs and gameplay mechanics. It was reviewed that when designing a verb on a physical input a game designer should be aware of the uncanny valley where the verb requires precise or delicate movements. After that, it was also reviewed that using a list of intended emotions in games could create a good gameplay mechanics. According to multiplayer augmented reality games observations, there are some emotions which should be included in every multiplayer augmented reality games. Apart from these emotions, it depends on each individual concept of gameplay. The gameplay mechanics was considered with game environment, features, and contents to create a complete face-to-face augmented reality game.

The last discussed point was the multiplayer issue. The study revealed that social scenarios in the game that could be divided into cooperative and competitive put a profound impact on the game mechanics and face-to-face interactions. It is discovered during the studies that participants feel more fun playing the game in a competitive setting than a cooperative one. However, a cooperative setting encourages participants to communicate more with each other. The face-to-face interactions in a cooperative setting are also easier to perform than in the competitive setting. There are also other minor factors which affect the overall gameplay experience such as size of space of gameplay and intimacy among players.

7.2 Future works

Although many perspectives of face-to-face augmented reality games have been covered and identified in this thesis. There are still several possible extensions that could be added further in the future works.

Firstly, as a face-to-face augmented reality game was developed to be studied in Chapter 4 and 5, the study could be expanded into many more genres of games. The game developed in this thesis is a simple game which should cover the major kinds of games. However, there might be some specific kinds of augmented reality games that face-to-face interactions, augmented reality, games, and multiplayer aspects do not apply to. Since this is unbeknownst at this moment, conducting studies in various kinds and genres of games could be one feasible way to expose these exceptions.

Secondly, the study in this thesis relied on the vision-based observations of augmented reality markers. The current state of the game was not acknowledged by all players because there is no connection between devices which could relay

the information among them. If there is a connection implemented to the system, the movements and interactions between devices could be more varied and it could yield more possible gameplay mechanics and differences in user experience and behaviours in each situation. This is worth to be explored more in the future.

Lastly, a game design process which was introduced in Chapter 3 is not a concrete game design framework yet. Since this is not a major aim in this thesis, the proposed game design process was only efficient enough for a face-to-face augmented reality game study. However, it is possible to delve into this topic and produce a sufficient game design process framework for most of the augmented reality games. Many parts can be improved such as how the game components are assigned to each card, how the cards are drawn, how the drawn cards are taken to the consideration in the design process, etc.

This concludes all the studies in this thesis.

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