Exploring Gamification Design and Virtual Marker Technique Under the AR Framework

Boyang LIU

October 2021

Waseda University Doctoral Dissertation

Exploring Gamification Design and Virtual Marker Technique Under the AR Framework

Boyang LIU

Graduate School of Information, Production and Systems
Waseda University

October 2021

ABSTRACT

Mobile e-commerce (M-commerce) is a type of e-commerce (electronic commerce) on the rise that features online sales transactions made using mobile devices, such as smartphones and tablets. M-commerce includes mobile shopping and mobile payments. The point system is a common loyalty program that rewards after payment. Combining the characteristics of mobile devices to design the next-generation point system may bring new advantages to mobile e-commerce. On the other hand, mobile devices are becoming more and more important in Augmented Reality (AR) applications. Mobile devices that can support AR are becoming more powerful and less expensive at a very rapid pace. The main purpose of this dissertation is to build a gamified e-commerce environment based on mobile devices and AR. To achieve the purpose, I conducted two major studies – the gamification design of the AR framework and the virtual marker technique. AR-based 3D character design was proposed into the point system and compared with text-based and 2D pet-based design in competition design of shopping behaviors. The competition-based point system provided dynamic feedback for users' shopping through users' competitive awareness. New input (i.e., mission) was added into the point system to encourage users to create value when shopping. Users can complete the mission according to their own preferences. Users obtained experience value (EXP) and upgraded their levels by completing missions while shopping and then competed in the system. It was found that AR-based 3D pet design motivated participants to complete more value creation activities in shopping compared with 2D and text- based design. Users were willing to spend more time using AR-based 3D pet design than 2D- and text-based design and gave better questionnaire responses for AR-based 3D pet design. On this basis, I expanded the new approach of integrating gamification and social interaction into the marker-based AR point system and explored the impact of gamification elements. The design of non-competitive interactions was added and short-term and long-term incentive designs were proposed. The methodology included: (1) using gamification to create a framework that satisfied the motivations of different users (mission) and to build emotional connections between users and the system with a pet-based design. To reward the completion of a mission, new feedback was designed, including value points and virtual food in addition to the 3D pet. 3D pets were used to represent pets instead of users themselves. The user got value points and upgraded the level by accumulating EXP after completing the mission. Value points can be used to purchase virtual food and help pets recover energy in the system (short-term incentive). In the end, the income, expenditure, and feeding of the pet created a positive cycle. The desire to take care of a virtual pet may establish an emotional connection between the user and the system; (2) tightly coupling social impact into the point system to establish long-term connections between users. Based on these game elements, the system provided channels for interpersonal communication (i.e., competitive and non-competitive interactions), which allowed users to engage in long-term interactions without binding social media. Users can interact with each other by pet-based competition or giving away virtual food in this system. The influence of missions, rewards, and social elements on users' online shopping behaviors were explored. It was found that pet-based feedback was effective at motivating users to participate and increasing their purchases, while the mission had a clear guiding effect on purchases. Social interaction was found to positively influence the use of the system and online shopping. In addition to the changes in the framework design of the point system, some other elements are also within our consideration. I consider supporting the simultaneous existence of physical cards and virtual cards. Therefore, a framework for linking physical cards and virtual cards should be established. A virtual marker technique was proposed to build a marker-based AR system framework where multiple AR markers, including virtual and physical markers, work together. Virtual markers were generated from physical template markers or existing virtual markers. Users can completely customize these markers and use them. Therefore, such a framework had the scalability to complete more complex functions. In addition, the virtual marker technique can be used to manipulate AR objects more conveniently, which enhanced the interactivity and scalability of the marker-based AR system. Multiple markers can be used as control commands as well as inputs and outputs. The user can arrange multiple markers in a specific order to create a program or connect markers through hand gestures, then the result was presented in the form of AR. It was found that after the introduction of the virtual marker technique, users can still complete the task in a short period of time and showed a good level of operation. In addition, users demonstrated a good cognitive understanding of the system when using the system that combined virtual and physical markers. With the emergence and development of AR shopping, the e-commerce environment of AR shopping should be considered. Our research introduced social elements and 3D avatars into the point system to build a gamified AR framework. The virtual marker technique was proposed to expand the interactivity and scalability of the AR framework.

Keywords: augmented reality; multiple marker cooperation; virtual marker; gamification; e-commerce; hand gesture; marker-based system; 3D avatar

ACKNOWLEDGMENTS

Time flies, and in a blink of an eye I also ushered in the final stage of my Ph.D. career. In the years of studying abroad, I have too many fond memories. The first person to thank is our professor Jiro Tanaka. Since I came to Waseda University, I have been following our professor. Our professor will also retire next year. Thank you very much for the careful guidance from my professor over the past six years, allowing me to grow from a layman to what I am now. I hope that our professor can keep healthy and happy every day. I am also very grateful to my school and all the professors because you have created a comfortable learning environment for us and given care and love to each student. Secondly, I want to thank my parents and family. Because of your support and trust, I can concentrate on completing my studies. For me, graduation is the end of a journey and the beginning of a new chapter. There is no doubt that the meaning of my efforts is to provide a better life for my parents and family. I am also very grateful to all iplab members and my friends at Waseda University. For a foreign student like me, living in a foreign country is not easy. When I first came to Japan, I couldn't even understand a single sentence in Japanese. At that time I could only rely on my friends. During the six years here, I was happy and in pain. I have made many friends here. On rainy days, we sit in the dormitory, drinking tea and talking. We went out together during the festival or weekend. We greeted the New Year in the heavy snow in Hokkaido and celebrated the master's graduation in Okinawa. Without your company, I think I might not be able to carry through these six years of life in a foreign country. We will go our separate ways and we may not get together again, but I will cherish this time with you. I sent away a group of friends every year during the graduation season. This time, it's my turn. I also thank my friends in China and other places. During the six years in Japan, you have given me support and help.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Introduction

E-commerce (electronic commerce) is the buying and selling of goods and services over an electronic network, primarily the internet. E-commerce is powered by the internet, where customers can access an online store to browse through, and place orders for products or services via their own devices. In the early years, the buying processes were usually concluded on a desktop device. But as mobile devices become an important part of our daily lives, mobile e-commerce has become more and more popular. Mobile e-commerce (M-commerce) is a type of e-commerce on the rise that features online sales transactions made using mobile devices, such as smartphones and tablets. M-commerce includes mobile shopping and mobile payments.

Loyalty programs are structured marketing strategies, designed by merchants to encourage people to continue to shop at or use the services of businesses associated with the program. The point system is a common loyalty program that rewards after payment. With the rise of mobile commerce, the traditional point system has also ushered in new changes. The traditional point system uses plastic cards or stamp cards to reward points. The next-generation point system is believed to combine mobile devices and e-commerce to provide a dynamic and new experience.

Combining the characteristics of mobile devices to design the next-generation point system may bring new advantages to mobile e-commerce.

On the other hand, mobile devices are becoming more and more important in Augmented Reality (AR) applications. Mobile devices that can support AR are becoming more powerful and less expensive at a very rapid pace. Marker-based AR provides us with good positioning accuracy. By moving physical markers, we can move AR content. On the other hand, markerless AR uses natural feature points of images or objects. Compared with marker-based AR, it looks more natural. However, sometimes we cannot move physical images or objects freely. Therefore, I propose a virtual marker technique. By realizing the virtual marker technique, we can solve the limitations of physical markers. We can achieve a good positioning accuracy of location and freedom of moving markers.

1.2 Research Background

1.2.1 Augmented Reality

AR turns the real environment around us into a digital interface by placing virtual objects in real-time. Unlike virtual reality, AR uses an existing environment and overlays new information on top of it, while virtual reality creates a completely artificial environment. The technical means it uses include multimedia, 3D modeling, real-time tracking and registration, intelligent interaction, sensing, and more [1].

AR is interactive in real-time. There are various interaction techniques in AR. Some AR head-mounted displays allow users to control virtual objects by gazing, gestures, voice commands, and even touching and grasping virtual objects with their hands [2]. Since AR contains many principles and practices, I will briefly introduce some of the key concepts as the background knowledge of the research.

Tracking, Calibration, and Registration

In the context of AR, three important terms are associated with the measurement and alignment of objects – tracking, calibration, and registration [3]. Tracking is a term used to describe dynamic sensing and measuring of AR systems [4]. Calibration is the process of comparing measurements made with two different devices, a reference device, and a device to be calibrated [5]. Registration in AR refers to the alignment of coordinate systems between virtual and real objects [6].

AR Displays

Visual AR displays can be categorized:

(1) Head-mounted displays

HMD is a display device worn on the head that can superimpose virtual content on the user's real-world view. The most common display mounting option currently in the market is optically see-through, in the form of glasses, and can be either monocular or binocular. AR headsets can also take the form of helmets.

(2) Handheld displays

Handheld displays use small computing devices with a display that users can hold in their hands, such as smartphones and tablets.

(3) Stationary displays

Stationary displays are displays that will not be moved during their typical use. Common AR systems in this category usually use computers with built-in or tethered cameras or webcams to track target objects.

(4) Projected displays

In this type, projectors are used to create spatial AR without any explicit displays. The projection is rendered directly on the surfaces of real objects. The projection cannot change the shape of the object but adds surface details and dynamic visual effects. And it can automatically fine-tune the alignment when the object moves.

Interaction

There are three principal components of interaction in AR systems: the user, the user interface and the virtual content [7]. A key consideration in the mainstream use of AR technology is the need for a suitable AR user interface that will allow end-users to interact intuitively and seamlessly with virtual content. There are many interaction interfaces, including those that use gesture-based interaction, tangible interaction, and multimodal interaction interfaces.

(1) User

Users are divided into two categories according to the level of interaction, passive users and active users. A passive user refers to a user who can view virtual content but not interact with it. An active user refers to a user who can interact with virtual content. The passive user can receive visual, audio, or haptic feedback from the virtual content in the AR system, while the active user can also interact with virtual content through the user interface via visual interaction, audio interaction, and haptic interaction.

According to the user environment, the AR system can be divided into two categories – single-user environment and multi-user environment. The target purpose of AR use determines whether it is a single user or multi-user system. In a single-user environment, only one user can view and interact with virtual content in the AR system. In a multi-user environment, virtual information is shared between users. Each of these systems has specific pros and cons. One advantage of a single user is its simplicity. There is no need for a network to share data between users, or security measures to protect the virtual content shared through a network. One issue that needs to be considered in a multi-user environment is the rules of operation and interaction.

(2) User interface

Frequently mentioned user interfaces include a tangible user interface (TUI), multimodal user interface and mobile interface [8]. The concept of tangible AR (TAR) was first introduced by Kato et al. to reduce the gap between the virtual object and the input method [9]. TAR uses physical objects to interact with the virtual content within AR systems. The visualization of virtual information on a physical object allows the physical object to be used as a controller to manipulate the virtual information. The multimodal user interface refers to the use of multiple-input methods to enhance interaction in AR systems. Previous research regarding multimodal interaction using speech and a 3D UI interface has shown that the combination of speech and gesture can provide intuitive and seamless interaction. There is also a need for new interaction techniques for mobile AR experiences. There are many important differences between using a mobile phone AR interface and a traditional desktop interface, such as different input methods.

(3) Virtual Content

Virtual content includes online and offline content. Online content refers to the shared virtual content, which uses a network to frequently update any changes done by any other user using the same AR system. AR systems with offline content do not have the capacity to share changes to the virtual content via a network.

1.2.2 Gamification

Gamification refers to the application of using game design elements and game mechanisms in a non-game context to enable users to solve problems and improve the contribution of users [10]. Commonly, gamification employs game design elements to improve organizational productivity, user engagement, and more. Lots of research about gamification indicates that a majority of studies on gamification reveal that it exerts a good effect on individuals. Certainly, the differences exist for different individuals and different contextual [11]. An individual's ability to comprehend digital content and understand a certain area of study such as music is improved by studies on gamification [12].

Differences from Games

Gamification is different from making a game. Gamification means applying game elements to a non-game domain. Typical game elements include points, badges, and leaderboards. Points are basic elements of a multitude of games. Badges display achievement. Leaderboards rank players according to their relative success. Gamification looks at how the game elements are applied in non-game frameworks to achieve certain results. It can offer game elements such as points, badges, and leaderboards as rewards.

A game is an activity or sport usually involving skill, knowledge, or chance, in which a player follows fixed rules and tries to win against an opponent or to solve a puzzle. Games can be classified in different ways. According to the forms, it includes sports, tabletop games, and video games. From the number of participants, it can be divided into single-player games and multiplayer games.

Therefore, although gamification applies game elements, the design of gamification applications and games can be different.

Techniques

The gamification techniques are aiming at leveraging people's natural desires for achievement, competition, socializing, or simply their response to the framing of a situation as game or play.

Andreas Lieberoth et al. [13] conducted studies that experimentally dissociates the psychological impact of framing versus game mechanics when presenting a serious activity as a game. Results demonstrate that the effects of simply framing the activity as a game through vernacular and artifacts hold almost as much psychological power as the full game mechanics.

Rewards are used by early gamification strategies for users who accomplish desired mission or competition to engage users. Rewards types include providing the user with virtual currency [14], the filling of a progress bar [15], achievement badges or levels [14] and points [16].

The paper written by Juho Hamari et al. [14] presents a framework for evaluating and designing game design patterns commonly called "achievements". From the perspective of the achievement system, an achievement appears as a challenge consisting of a signifying element, rewards, and completion logics whose fulfillment conditions are defined through events in other systems (usually games). From the perspective of a single game, an achievement appears as an optional challenge provided by a meta-game that is independent of a single game session and yields possible reward. Making the rewards for providing leader boards or accomplishing tasks visible to other players are ways of encouraging players to compete [17]. Another method of gamification is to make the existing missions or tasks feel more like games [18].

The review written by John Rizzo et al. [17] says that motivation, created by game attributes such as timely feedback, teamwork, collaboration, problem-solving, a sense of presence through avatars, vivid designs, and even virtual economies are used by the authors to support their thesis that businesses will need to begin to make work more like games in order to keep employees engaged and increase the bottom line.

The book *Reality is Broken* written by Jane McGonigal et al. [19] explains the science behind why games are good for us–why they make us more creative, more resilient, and better able to lead others in world-changing efforts.

Game Mechanics

Game mechanics consist of methods or rules designed for interaction with the game state and therefore provide gameplay [20]. Mechanics are used by all games; however, styles and theories differ as to their ultimate importance to the game. In general, the study and process of game design, or ludology, are efforts to come up with game mechanics that allow for people playing a game to have an engaging but not necessarily fun experience.

The interaction of various game mechanics determines the level and complexity of player interaction in the game, and in conjunction with the resources and game's environment determine game balance. Games have used some kinds of game mechanics for centuries, while others that have been invented within the past decade are relatively new.

Complexity in game mechanics should not be confused with depth or even realism. Go is probably one of the simplest of all games but it shows an extraordinary depth of play. Most video games or computer feature mechanics, in terms of making a human do all the calculations involved, are technically complex even in relatively simple designs.

In general, commercial video games, as processing power has increased, have moved from simple designs to extremely complex ones. In contrast, casual games have generally featured a return to puzzle-like, simple designs although some games are becoming more complex. In physical games, differences generally come down to style and are somewhat determined by the intended market.

1.3 Motivation and Objective

I am interested in how to build an AR framework on mobile devices to promote the development of mobile e-commerce. This research selected the current point system as the research object. With the popularization of mobile devices, the integration of point systems to mobile devices can be valuable. Compared with traditional plastic cards or stamp cards, mobile devices have obvious advantages, such as a system structure that can be quickly updated and maintained, and a dynamic and attractive interactive experience. Therefore, I propose an AR framework based on mobile devices to combine the advantages of mobile devices.

The current point system has some shortcomings: (1) uncertain user–system connection. A point system rewards the consumption of users through financial incentives, but rarely considers their motivation and emotional needs; (2) insufficient social connection. The main social loyalty actions include referring friends and sharing a brand or product with friends through social media. However, these actions are only one-time sharing activities and cannot facilitate long-term social connections. Furthermore, social media and the point system are not tightly coupled, which may weaken the impact of social connection. The advantages of mobile devices can be combined to solve the above problems. For the first question, we can establish an emotional connection between the system and the user. Regarding the second question, strengthen user participation by introducing social connections between users. However, there are still many problems in how to design a reasonable combination of gamification and AR framework. Gamification design includes a variety of game elements. When designing a gamification framework, what elements can be used and their impact remains to be explored.

In addition to the changes in the framework design of the point system, some other elements are also within my consideration. Traditional point cards still play an important role in daily life. The system should consider supporting traditional point cards and creating value for their use. At the same time, with the development of mobile point systems, virtual point cards are becoming more and more common. I consider supporting the simultaneous existence of physical cards and virtual cards. Therefore, a framework for linking physical cards and virtual cards should be established.

In the early stage of my research, my focus is the combination of gamification design under the AR framework. AR is a new interactive technology. Gamification is the application of game-design elements and game principles in non-game environments. The question of how to combine the two to create a system framework that attracts users is research that needs to be conducted. The 3D avatar may provide dynamic feedback effects in AR systems and become a suitable design element. Therefore, I first explored the use of 3D avatars under the AR framework in the competition design of shopping behavior. By comparing AR-based 3D character design with traditional text-based and 2D pet portrait-based design, I found the potential effects. Then, I use 3D avatars and combine multiple gamification elements to design a multi-user AR framework. Based on the new framework, I conducted research to understand the influence of various elements on user shopping behavior. This provides a reference for how to apply gamification elements to the AR framework design.

In addition to the research on gamification elements under the AR framework, I also consider solving the technical problems in the AR framework from the level of interaction. I propose a virtual marker technique to build a multi-marker AR system framework where multiple AR markers, including virtual and physical markers, work together. Virtual markers are generated from physical template markers or existing virtual markers. Users can completely customize these markers and use them. Therefore, such a framework has the scalability to complete more complex functions. In addition, the virtual marker technique can be used to manipulate AR objects more conveniently, which enhances the interactivity and scalability of the marker-based AR system. I divide the cooperation of multiple markers into two categories—one is an ordered series of markers, such as that used in tangible programming, and the other is an unordered series of markers. Multiple markers can be used as control commands as well as inputs and outputs. I have implemented a prototype system to illustrate the framework. The user can arrange multiple markers in a specific order to create a program or connect markers through hand gestures, then the result will be presented in the form of AR.

In general, my research explores the AR framework from several different aspects of interface design and interaction design. The research goal is to establish a mobile AR gamified point system based on the virtual marker technique. In Chapter 2 and Chapter 3, I mainly focused on gamification design and the influence of gamification design on user behavior in the point system. I proposed an AR framework that combines virtual markers and physical markers to provide technical support for point system in Chapter 4.

1.4 Organization of the Dissertation

The dissertation consists of 5 chapters, which are organized as follows:

Chapter 2 introduces the study of the use of 3D avatars in competition design of shopping behavior. I compared AR-based 3D character design with traditional text-based and 2D pet portrait-based design in a gamified shopping process. I conducted an evaluation to understand the potential impact of using a 3D avatar in an AR framework on user shopping behavior.

In **Chapter 3**, I explore a novel approach to integrate gamification and social interaction into a point system based on marker-based AR. The methodology includes: (1) using gamification to create mission frameworks that satisfy the motivations of different users and to build emotional connections between users and the system with a pet-based design. (2) Social impact is tightly coupled into the point system to establish long-term connections between users. I performed two experiments to examine the effects of game elements and social cues.

In **Chapter 4**, I propose a virtual marker technique to build a marker-based AR system framework where multiple AR markers, including virtual and physical markers, work together. Virtual markers can be customized by users and used to program or control AR objects. I conducted a pilot study on the marker-based system that introduced the virtual marker technique to understand its potential value in an AR system.

In **Chapter 5**, the dissertation will be concluded, and the future work will be discussed.

Chapter 2

The Use of 3D Avatars in Competition Design of Shopping Behavior

2.1 Background

3D avatar is widely used in various researches, such as chat bots or remote collaboration [21, 22, 23, 24]. In these studies, 3D avatars acts as agents to provide natural interaction. The 3D avatar is also an important element in the game. The 3D avatar can be used as the avatar of the user to make the user feel immersed in the game. However, few studies clearly show what advantages 3D avatars can provide in social systems. Therefore, it is valuable to understand what kind of influence a 3D avatar can have in a social system.

This research aims to understand whether the AR-based 3D character competition design has advantages in influencing user engagement and user perception compared with general competition designs. Specifically, I compared AR-based 3D character design with traditional text-based design and 2D pet portrait-based design in competition design of shopping behaviors. Competition systems are users' shopping feedback. Users obtain experience value (EXP) by completing shopping tasks while shopping and then compete in the competition system. I have designed three different competition interfaces. In the first competition interface, the user's level is displayed in the form of a traditional leaderboard (i.e., baseline condition). In the second competition interface, the 2D static portrait was used as a stand-in for the user. In the third competition interface, the 3D avatars placed in the AR environment were used to give users dynamic competition feedback. Users used three systems with different competition designs for shopping activities.

2.2 Related Work

Many gamified systems based on competition are proposed for improving user motivation. In this section, I describe the related works in detail and their limitations, also the advantage of my proposed method with the works. In order to improve the competition design, I consider combining 3D avatars and understanding pet-based gamified systems. The relationship between the related work and my proposal is shown in Figure 2.1.

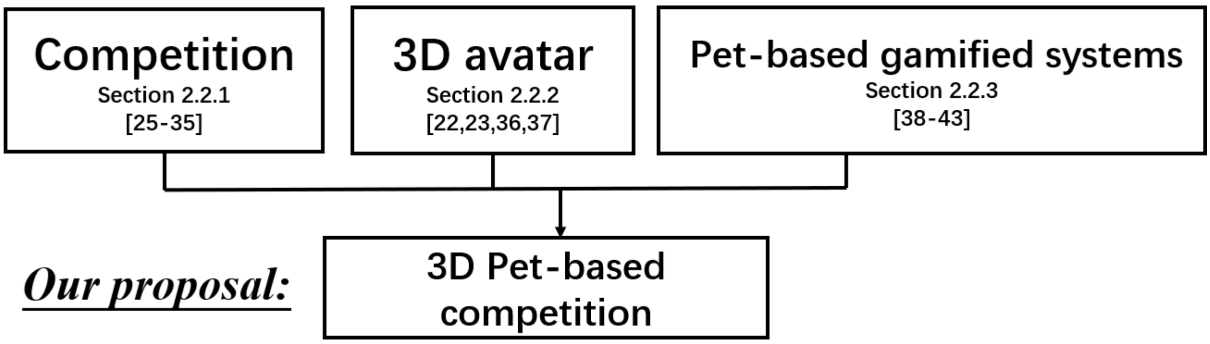

Figure 2.1 The relationship between the related work and my proposal.

2.2.1 Competition

Early demonstrations of gamification emerged prior to 2008 in the fields of consumer advertising and corporate training. The term "gamification" first gained widespread usage in 2010, in a more specific sense referring to incorporation of social/reward aspects of games into software.

Competition is an effective form of social interaction in gamification that stimulates the user's internal motivation. Many gamification systems are designed based on competition. A large number of studies have proved that the competitive environment can improve user performance and promote intrinsic motivation compared to a single-player environment [25, 26].

Common competitive designs are usually based on leaderboards [27]. Park et al. [28] used leaderboards to assist learners in goal setting and unleash the motivation for learning and Jagušt et al. [29] compared 4 conditions (a non-gamified and competitive, adaptive, and collaborative gamified conditions). The competitive design was based on a leaderboard. These research focused on the use of leaderboard-based design to improve user performance. However, the leaderboards have limitations and require changes for specific situations.

Some gamification systems propose different types of leaderboards. Morschheuser et al. [30] compared different types of leaderboards for inter-team competition for the top 10 contributors in each team and competition for the top 10 individual users. This leaderboard design combines the design of the team and the individual to provide a competitive experience in different situations. Akhriza et al. [31] proposed a new leaderboard using a dartboard-like model to replace linear traditional leaderboard. The pathways are then visualized circularly using the proposed dartboard model so that the career paths of all educators can be seen effectively.

But the design of the leaderboard can still only display the static data information of the user, and cannot provide a dynamic interactive experience. Therefore, some studies have tried to explore visual images instead of providing a more attractive competitive environment.

In the research of Li et al. [32], each player competes against another online player to complete a drafting task using AutoCAD. The real-time progress of the player and the opponent is visualized in real-time using two progress bars. Users can easily compare their own progress bars with their opponents to compete. The design of this progress bar is unique. It may be a reasonable design for an environment with obvious time or end characteristics, but it is difficult to widely apply it to other competitive systems.

Tausch et al. [33] compared cooperative and competitive visualizations for co-located collaboration. In the competitive condition, each participant is represented with a differently colored balloon. Lin et al. [34] created a social computer game, which links a player's daily footstep count to the growth and activity of a fish. Both of these studies show users in a visual form, allowing users to participate in the competition in a more interesting way. But they did not pay too much attention to how users should be visualized. In other words, different studies can take different forms to visualize users. In addition, competition can bring about incentives and negative effects. The above research did not pay attention to what kind of design can eliminate the negative impact of competition.

Chen et al. [35] proposed the notion of surrogate competition, which eliminated direct competition among students by a surrogate competitive design using 2D pets instead of a direct competitive design using 2D user avatars.

These competition systems are all based on 2D images. My research attempts to extend the 2D pet surrogate competition to an AR-based 3D avatar competition to provide a more realistic and interesting feedback experience. At the same time, the 2D surrogate competition was expanded from a two-player competition design to a multiplayer design to provide static information display capabilities similar to leaderboards. I consider exploring the value of AR-based 3D alternative to competitive design, and understand whether it has an advantage over other competitive designs (i.e., 2D-based and text-based).

2.2.2 3D Avatar

An avatar is a graphical representation of a user or the user's character or persona. It may take either a two-dimensional form as an icon in Internet forums and other online communities or a three-dimensional form, as in games or virtual worlds.

The earliest use of the word avatar in a computer game was the 1979 PLATO role-playing game Avatar [36]. The use of the term avatar for the on-screen representation of the user was coined in

1985 by Richard Garriott for a computer game. Now, 3D avatars are widely used in various scenes including communication programs, video games, and non-gaming online worlds because of their stereoscopic and realistic characteristics.

It can be used for communication between the user and the computer to provide the user with a more realistic interactive experience. A design of a chatbot was proposed with avatar and voice interaction to make a conversation more alive [22]. The computer rendered an avatar whose gesture and lips were in sync with the audio reply.

Compared with the traditional interaction between users and the system, the interactive mode based on 3D avatars can provide more dynamic and realistic feedback. Therefore, 3D avatars will not only be used for interaction between a single user and the system, but also designed to support communication between multiple users.

An implementation of a real-time dynamic 3D avatar from multiview cameras was presented for immersive telecommunication [23]. The user could be immersed and has natural interaction with remote participants. 3D avatars have demonstrated the advantages of verbal and nonverbal social interaction by providing embodied social presence [37].

Considering that 3D avatar plays an important role in social interaction, 3D avatar-based designs for competition may have advantages compared to the general design. However, whether 3D avatars are more valuable than other competition design is still an unexplored task. My research proposes to apply 3D avatars to a competitive design to provide dynamic feedback and compare it with other competitive designs to understand whether such design has advantages.

2.2.3 Pet-Based Gamified Systems

A digital pet (also known as a virtual pet, artificial pet, or pet-raising simulation) is a type of artificial human companion [38]. They are usually kept for companionship or enjoyment. People may keep a digital pet in lieu of a real pet. Cyberpet and Tamagotchi were some of the first popular digital pets [39].

Due to the popularity of virtual pets, many gamified systems have adopted a pet-based design to attract user participation. A pet-based gamified system motivates users to perform at a higher level through the emotional attachment of humans towards pets [40]. In fact, this incentive effect has been proven to have a positive impact in different scenarios [41, 42, 43].

In learning, it has been proven to promote learners' self-awareness, learning motivation, and willingness [44]. Orland et al. [42] implemented and tested the effectiveness of a virtual pet game designed specifically for energy use reduction in a commercial office setting and demonstrated that game participants decreased their plug load energy consumption.

In exercise, it has been proven to promote users to cultivate awareness of exercise. Pollak et al. [43] discussed the "Time to Eat" mobile-based game using a virtual pet to incite adolescents to change their eating behavior and claimed pet-based games can motivate children more than classical entertainment games without clear objectives.

These gamified systems used pet-based designs to create emotional bonds with users and influence user behavior. Inspired by these studies, I attempted to combine point system and pet-based designs to establish emotional connections between users and the system and positively influence consumer shopping behavior. The above-mentioned research mainly focuses on using pets as the dynamic feedback of the system. In my research, I not only use pets as dynamic feedback, but also participate in social interactions among users as a substitute for users' competition.

2.3 System Design

2.3.1 Overview

I used different competition designs in point systems to study whether the use of the 3D avatar can better motivate users' shopping behavior. Traditional point systems use financial incentives to retain consumers and encourage purchases. Although financial incentives are an important means to retain users, there is usually a lack of other incentives. There are many other considerations in terms of consumption, such as where the product is produced, whether the product is environmentally friendly and whether it is good for health. These value factors that may have personal and social value are not reflected in the traditional point system. I explore the application of non-financial incentives (i.e., gamification) as a supplement to traditional point systems to encourage value creation activities in consumption. Gamification converts value creation into shopping missions and encourages users to complete missions through competition feedback to gain enjoyment from shopping and maintain a healthy lifestyle. A shopping process with a gamified point system is proposed (see Figure 2.2).

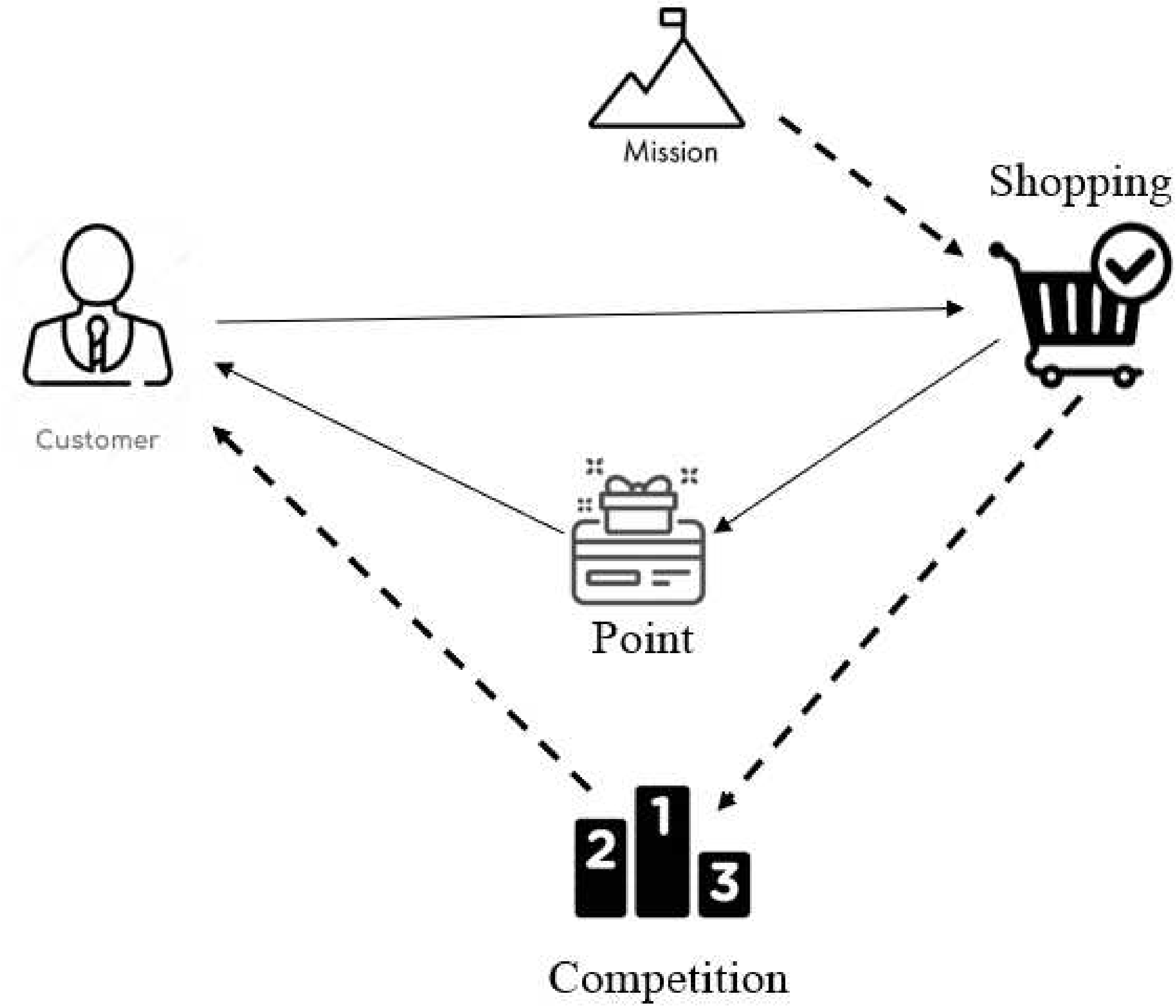

Figure 2.2 A shopping process with a gamified point system. The solid line represents the shopping process with traditional point system. After consumption, points are given to consumers to motivate repeat purchase. The dotted line indicates the new game elements (mission and competition) in the gamified point system. If the user purchases a product that meet the requirements of the mission, the corresponding mission will be considered completed. The user will be rewarded for level upgrades in the system and gain social recognition by participating in competition. On the whole, users create value (mission) in consumption, and get feedback from competition which engages consumers in a more socially conscious behaviors.

2.3.2 Mission Design

The mission is to designed for value creation activities. I predefined three missions for shopping in the system based on sustainable development (i.e., the purchase of environmentally friendly goods, the purchase of healthy foods, and the purchase of local goods) [45]. The main goals of missions include following aspects: (1) impact on society and environment; (2) building the personal lifestyle of consumers; and (3) a framework for future personalized services combining user information and purchase records. Although mission is pre-defined in the current framework, it has the potential to be expanded in the future. Specifically, users can input their own characteristics or preferences. The system can give a matching mission list according to the user's characteristics or preferences. It may help establish a new relationship between the user and the system and promote the user's use of the system.

Users can view the content of the missions and the number of completed mission from the mission interface in the system (see Figure 2.3).

Figure 2.3 Mission interface. The left side of the mission interface shows the mission of the day. In the middle of the interface, the number of mission the user has completed so far is displayed.

The condition for completing the mission is to choose the products that meet the requirements during shopping (i.e., healthy foods, environmentally friendly goods or local goods). The mission can be failed. If the mission is failed, the user will get no rewards for the mission. This design allows users to freely complete mission according to their own wishes. If the user has completed the mission, they can receive experience value (EXP). If the EXP reaches a certain threshold, the user's level will increase. The role of level is to serve as a criterion for user competition. Therefore, if users want to win the competition, they need to complete more mission. Users gain social recognition in the virtual world as the results of completing value creation activities in the real world. The desire for recognition can promote and sustain the motivation for completing mission. In the end, value creation (mission), level, and competition create a positive cycle.

2.3.3 Comparing AR-based 3D characters with 2D- and text-based representations

different competition designs are provided for users to interact with other users after shopping. Each competition design has a different display designed to provide users with a series of visual representations. All competition designs are asynchronous (i.e., when a user wants to compete with other users, other users do not need to participate in real time). It allows users to gain experience from the competition anytime, anywhere.

Leaderboard (Text-Based)

The design aims to simulate traditional competition displays [46]. Users willing to participate in the competition will be included in a name list, which is considered to allow other users to access their level information. The system gets the user's level information from the database and turns it into a text-based competition, with a leaderboard that covers all friends who have also opted in (see Figure 2.4). The list is divided into three columns, namely ranking, level and user name. The list is sorted according to user level. The user with the highest ranking will be displayed in the first row with a golden icon before the ranking.

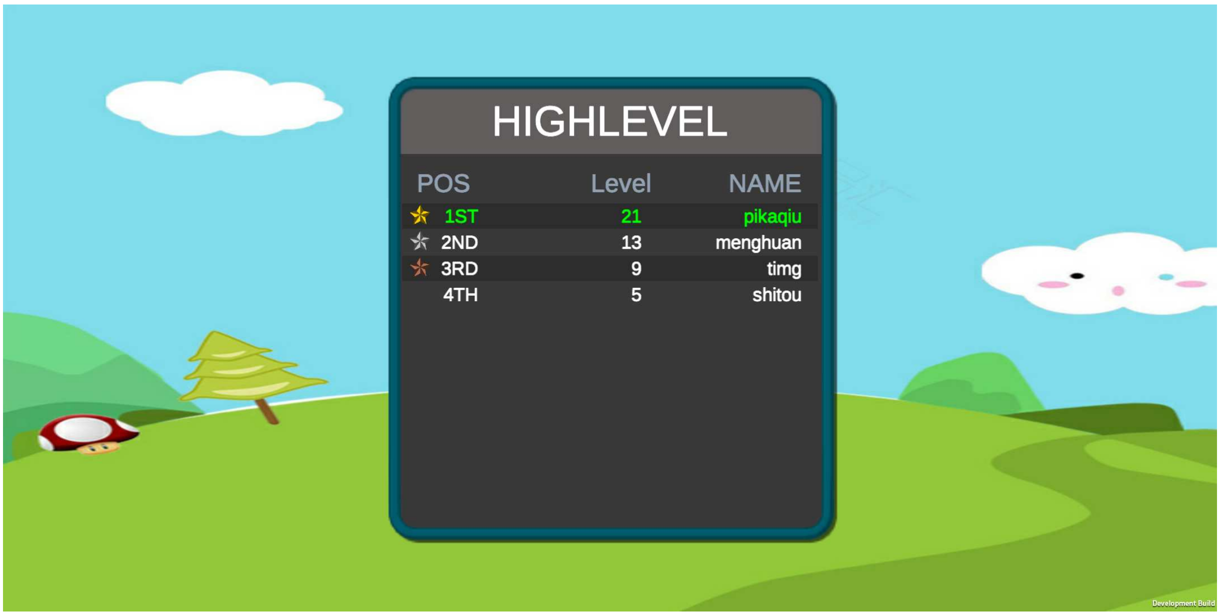

Figure 2.4 Competition interface with leaderboard. The user's level information and ranking are displayed in text form on the leaderboard without the visual characters.

2D Representation in Non-AR environment

For this competition design, I adopted a compromise design between text-based design and 3D representation, using 2D pet portraits. I provide three kinds of pet portraits as representatives of users, namely the cat, the dog and the turtle. Considering that the design uses 2D portraits, I adopted a static design for pets. In other words, pets are designed as static 2D characters. In addition, I use a 2D background as the environment to prevent the mismatch between the 3D background and the 2D static portrait. In order to reduce the difference between this design and the text-based design, which may influence the comparison, I use the same 2D image as the background. The user name and level information are displayed next to the pet. Users can know the level of their pets as well as the levels of other users. Based on the level information, the system will give a ranking. A golden crown will be displayed on the head of the pet with the highest level. Similarly, the silver crowns and bronze crowns will be displayed on the top of the second and third places (see Figure 2.5). Using 2D visual representations instead of textual forms may give users a stronger sense of substitution, which can inspire better performance compared to text-based design.

Figure 2.5 Competition interface with 2D representation. The crown corresponding to the ranking is displayed on the top of the representation's head. In the figure, two users choose cats as their 2D representation, one chooses dogs, and one chooses turtles.

3D Character in AR Environment

In this design, the user is visualized as a 3D pet in the system. Same as the 2D-based design, I provide 3D models of the cat, the dog, and the turtle. Considering the attributes of 3D characters, I use AR technology to extend the environment of 3D pets into the real 3D space instead of using 2D pictures as virtual backgrounds.

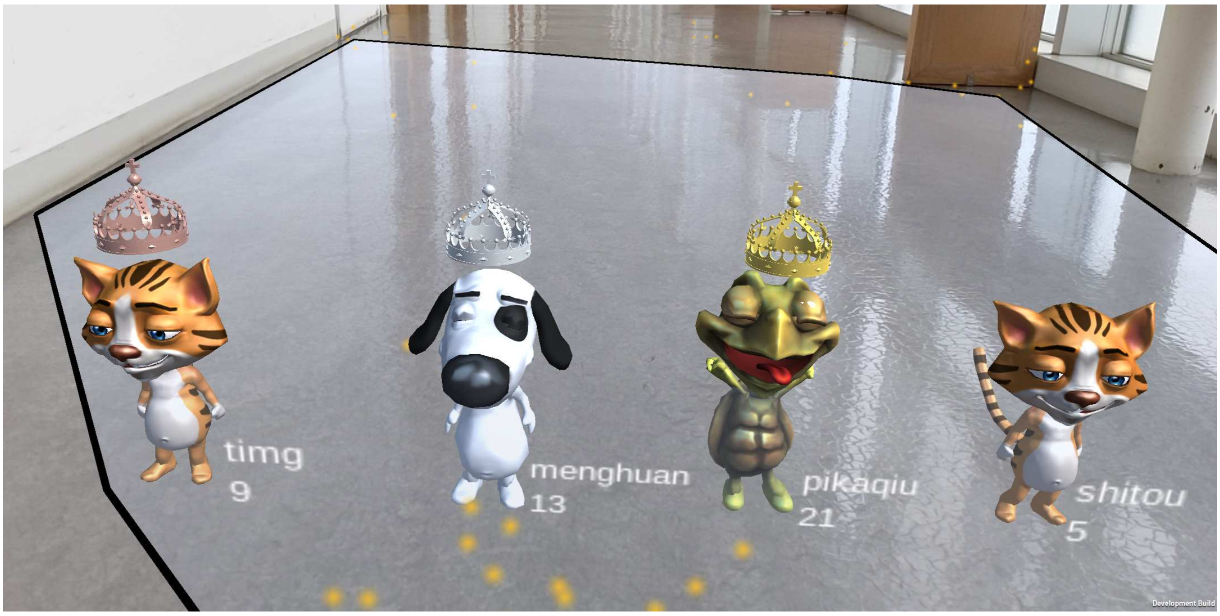

Figure 2.6 Competition interface with AR-based 3D characters. The user name and level are displayed next to the pet. The pet with highest level wears a gold crown, while the pet with the second highest level has a silver crown, and the pet with the third highest level has a bronze crown.

The AR technology used mainly includes point cloud visualization, plane detection and the placement of the 3D virtual pet on the plane. The user scans the plane through the phone's camera. When the feature points are identified, they are visualized as yellow points. Feature points are typically notable features in the environment that the device can track between frames. A point cloud is a set of feature points which can change from frame to frame. When the plane is detected, the plane is visualized as a transparent plane. The user can tap the detected plane on the screen to place 3D pets at the intersection of the ray and the plane. The user name and level information are displayed near the corresponding pet. According to the number of completed missions, the level of the user's pet will change. Users can use their pets to compete with other users. According to the ranking result, the system will display the crown on top of the pet's head. The pet that wins the first place will make happy action to provide dynamic feedback (see Figure 2.6).

2.4 System Implementation

2.4.1 System Hardware

The main hardware devices used for the development of the prototype system included a laptop and smartphones. The laptop was used to build the system and works as a server. Smartphones were the mobile devices used to install the client. Windows 10 Home Edition was installed on the laptop. The processor was an Intel(R) Core(TM) i7-6500U CPU @2.50 GHz, and the laptop had 8 GB RAM.

2.4.2 Development Environment

The development operation system is Windows 10 Home Edition. The development software was Unity 2019.2.11f1 (64-bit), a cross-platform game engine [47]. Unity 3D was used to build and render the AR system. The Vuforia SDK was used for the AR implementation. For the server, I deployed WampServer Version 3.0.6 32 bit, consisting of the Apache web server, OpenSSL for SSL support, and MySQL database. Apache and MySQL were kept running on the laptop. Communication between Unity 3D and MySQL was implemented in the PHP programming language. I mainly used C# Programming Language as the script language to realize the system in Unity.

2.4.3 Overall System Structure

To realize this multi-user system, I created the following system architecture as shown in Figure 2.7.

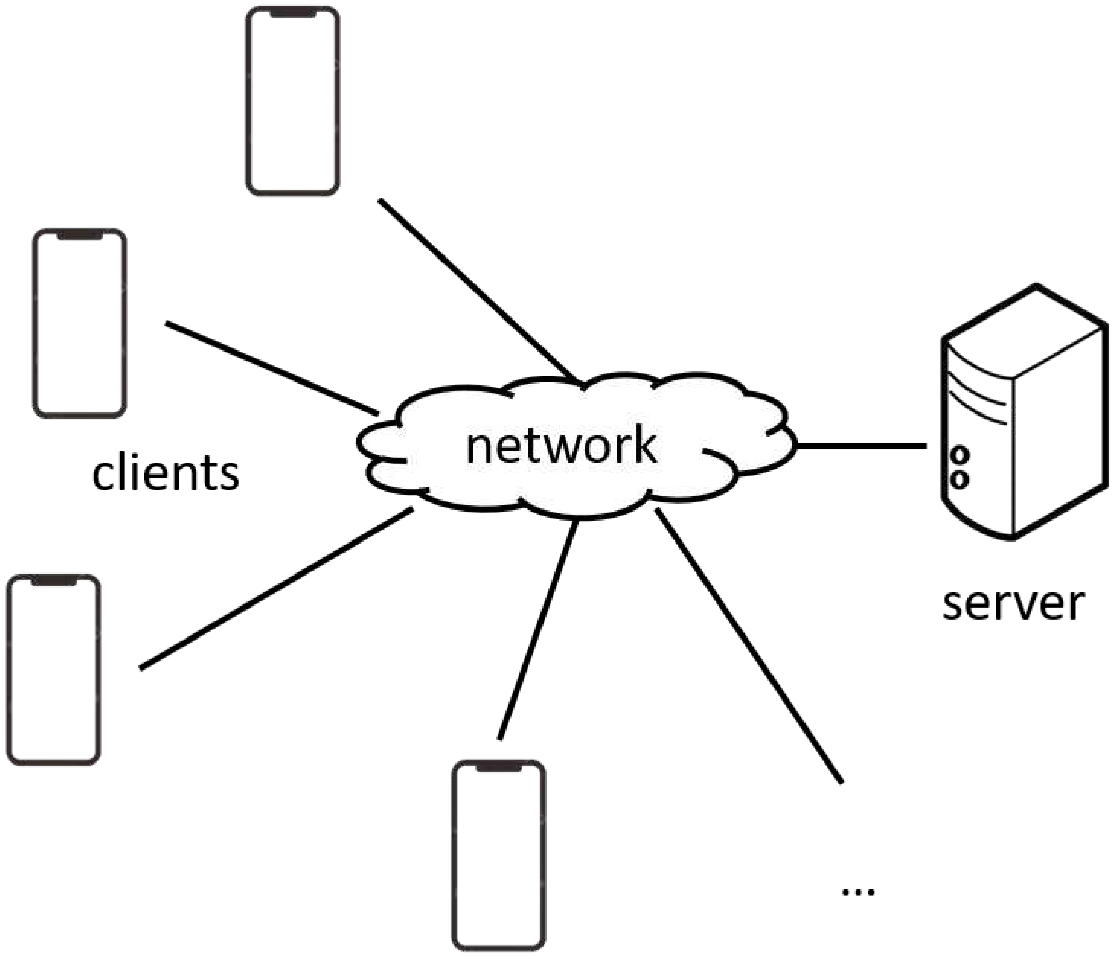

Figure 2.7 Multi-user system structure. Users connect through the network and obtain level information from the database for competition.

Users can participate using a mobile device, such as a smartphone. Every user connected to the server constantly receives data, locally creating a representation of the game state. If a user performs an action, a client wil send a request to request the database information, where the form is sent to the php script file for processing. I used the WWW and WWWForm classes to send and receive requests between Unity and the server.

After the web server receives the request for information, it retrieves the file and passes it to the PHP engine for processing.

The PHP engine begins to parse the script. The script mainly includes commands to connect to the database and execute queries. PHP initiates the connection to the MySQL server and sends the appropriate query to that server.

The MySQL server receives the database query request, starts processing the query, and returns the query result to the PHP engine.

After the PHP engine finishes running the script, it returns the data to the server. The server then returns the data to the client. When receiving from the database, the information was converted into JSON format and received.

After receiving, it was decoded into a string format according to the class defined. According to the string information, the status of the user client will be updated to display the current user information.

2.4.4 Interface Implementation

I have implemented three systems (see Figure 2.8). Each system contains three interfaces, and the system has built-in buttons to connect to the same shopping website. The main difference between each system is the competition interface. I will introduce the implementation of each interface in detail.

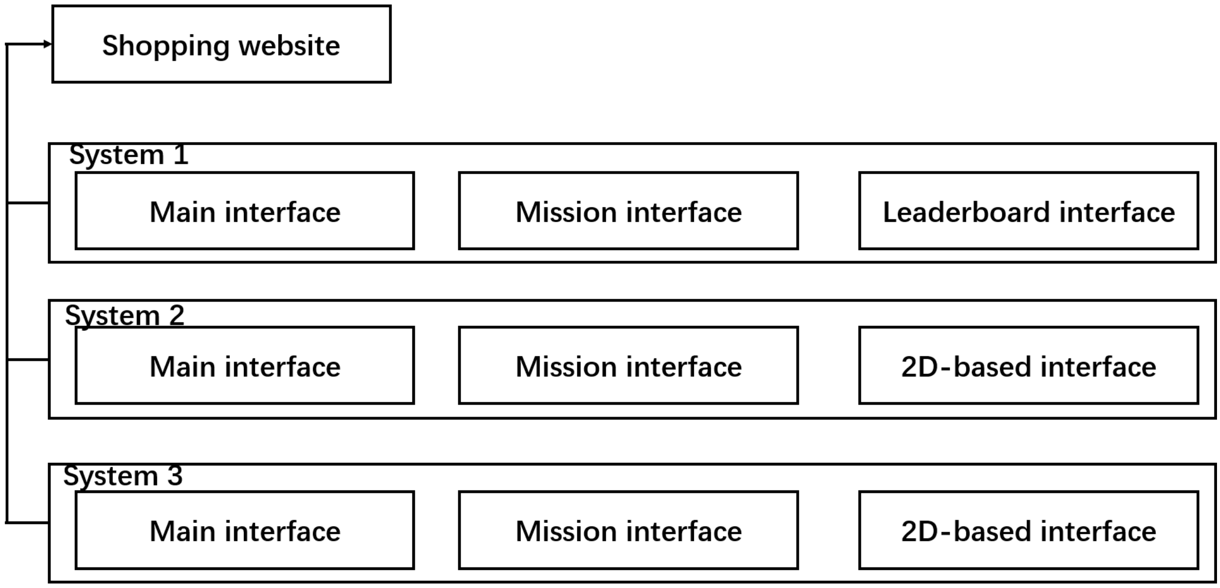

Figure 2.8 Three systems implemented for the comparison.

Main Interface

Figure 2.9 shows the implementation of the system main interface in Unity. The implementation of the system main interface is divided into two parts, canvas and background. In the background part, I chose the same background pattern as the leaderboard and 2D-based design to maintain the coordination of the system. The canvas part contains different buttons corresponding to different functions (see Figure 2.10). The button on the left is the button that connects to the shopping website. The upper button on the right connects to the mission interface and the lower button connects to the competition interface. The interface remains the same in the three systems, and the shopping webpage and mission interface are also the same. The difference is that the interface entered through the competition button is different in the three systems.

Figure 2.9 Implementation of main interface in Unity.

Figure 2.10 Canvas part of main interface.

Leaderboard Interface

Figure 2.11 shows the implementation of the leaderboard interface in Unity. In Unity, I set the format of each row, namely pos, level, and name. The game object corresponding to each row is named highscoreEntryTemplate, which contains child objects named posText, scoreText, nameText, and trophy. When multiple users participate in the competition, the system will instantiate multiple rows according to the number of users. When multiple users participate in the competition, the information of each user will be obtained from the database and filled in each row according to the defined format. The system will obtain the information of each user from the database and fill in the child objects in each row according to the defined format. Finally, the system will sort according to the user's level information, and display all users' information in the order from high to low.

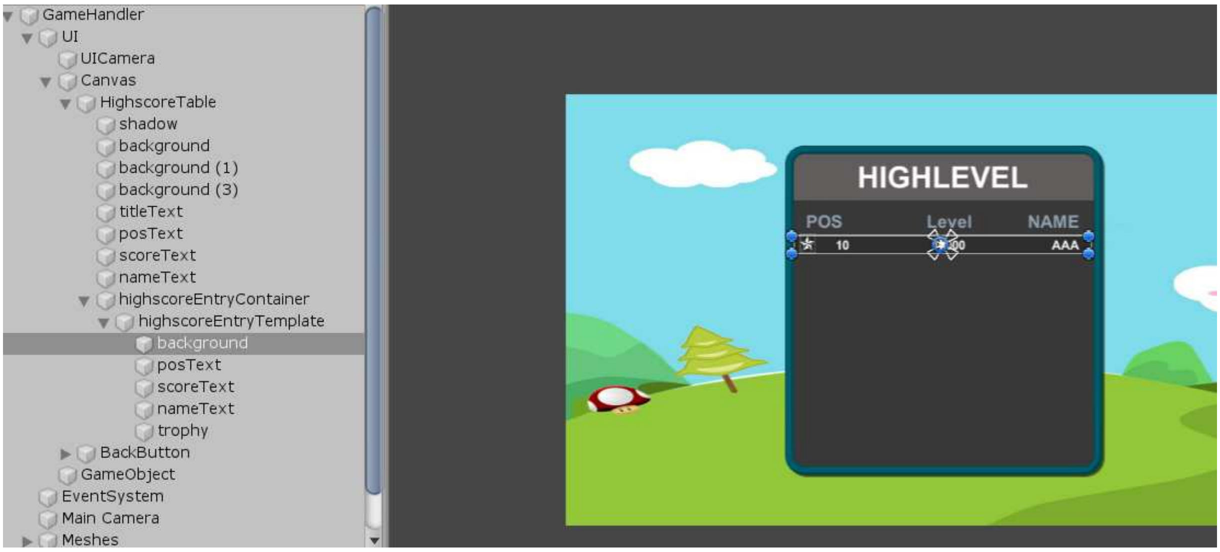

Figure 2.11 Implementation of leaderboard interface in Unity.

2D-based Interface

Figure 2.12 shows the implementation of the 2D-based interface in Unity. In the 2D-based interface, I set positions for multiple users from left to right. Figure 2.13 shows several components included in each user game object, including the 2D image, user name, level, and the crown above the 2D image. When multiple users participate in the competition, each user's information will be obtained from the database, and the user's image, user name and ranking will be updated according to the defined user interface structure settings. Finally, the system will sort according to the user's level, and the corresponding crown image will be displayed above the user's 2D image based on the sorting result.

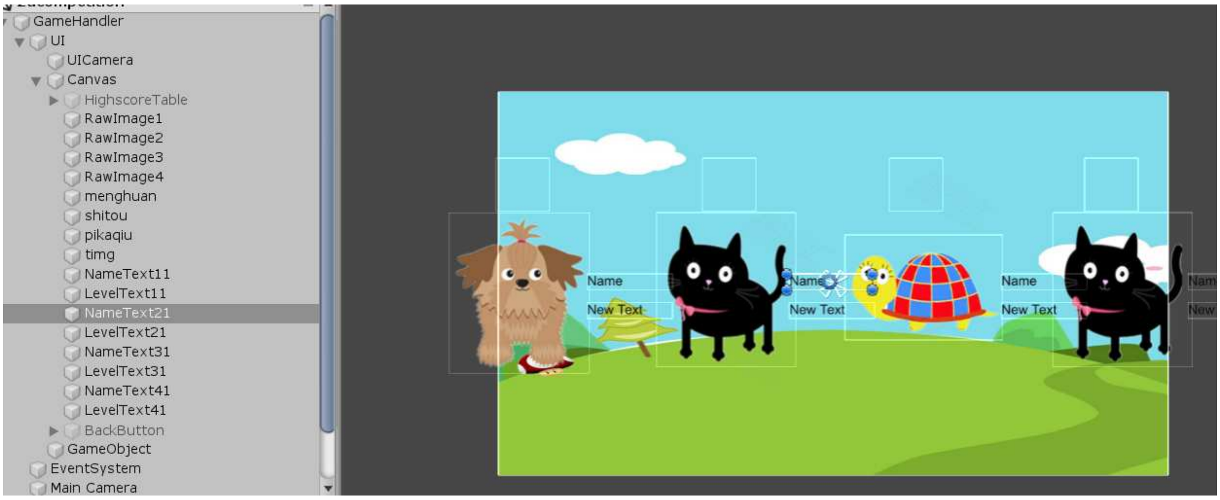

Figure 2.12 Implementation of 2D-based interface in Unity.

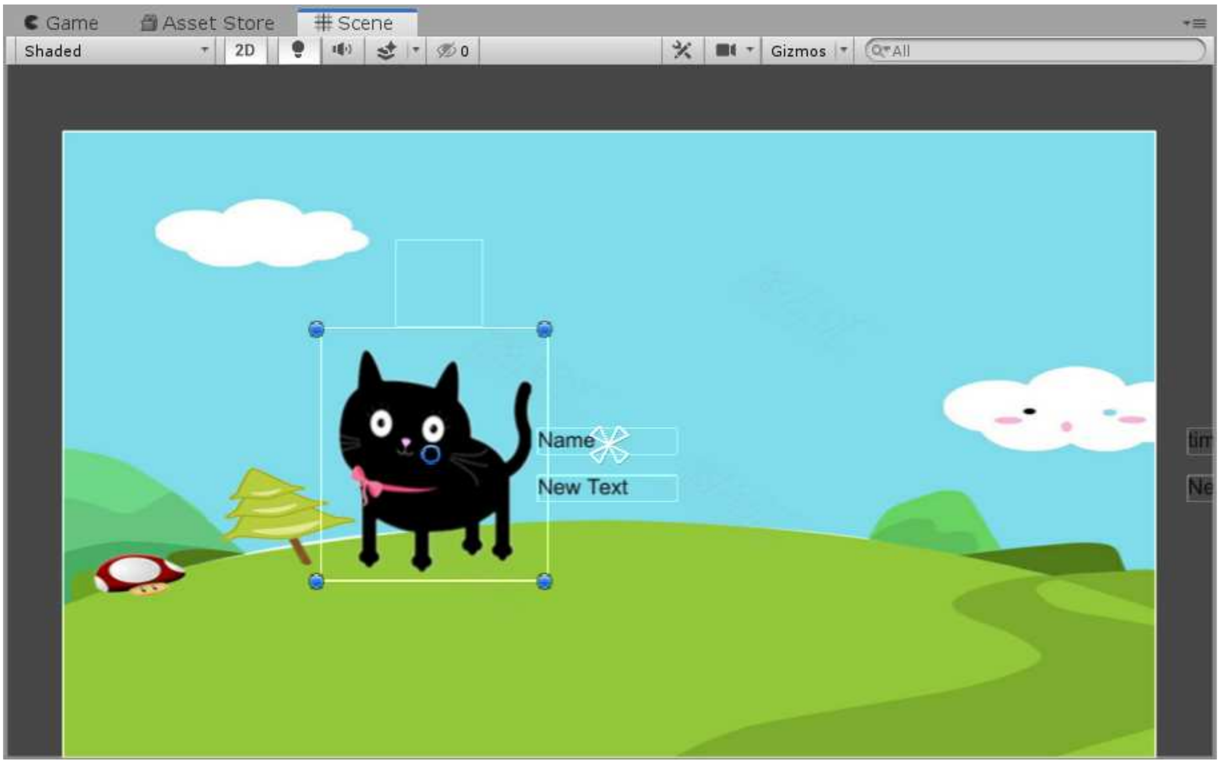

Figure 2.13 Components included in each user game object including 2D image, user name, level and crown image.

AR pet-based Interface

Figure 2.14 shows the implementation of the AR pet-based interface in Unity. In the AR pet-based interface, I use markerless AR. Multiple scripts are bound to the game object named AR session origin. The PlaceOnPlane script defines the operations that users can place virtual pets when they click on the plane. The other scripts are bound to define the user can visualize the plane through the point cloud and allow the user to click on the screen to send a ray to determine where to place the virtual pet.

The structure of each user includes a 3D avatar, user name, level, and the invisible 3D crown on the pet's head, as shown in Figure 2.15. When the user clicks on the plane to place the 3D avatar, the information of each user will be obtained from the database, and the user name and level boxes in the 3D avatar settings will be filled in. Finally, the system will sort according to the user's level, visualize the crown on the pet's head and render the crown according to the ranking order. I have attached an action for each pet. According to the ranking order, the first pet will call the script to control the pet to give action feedback.

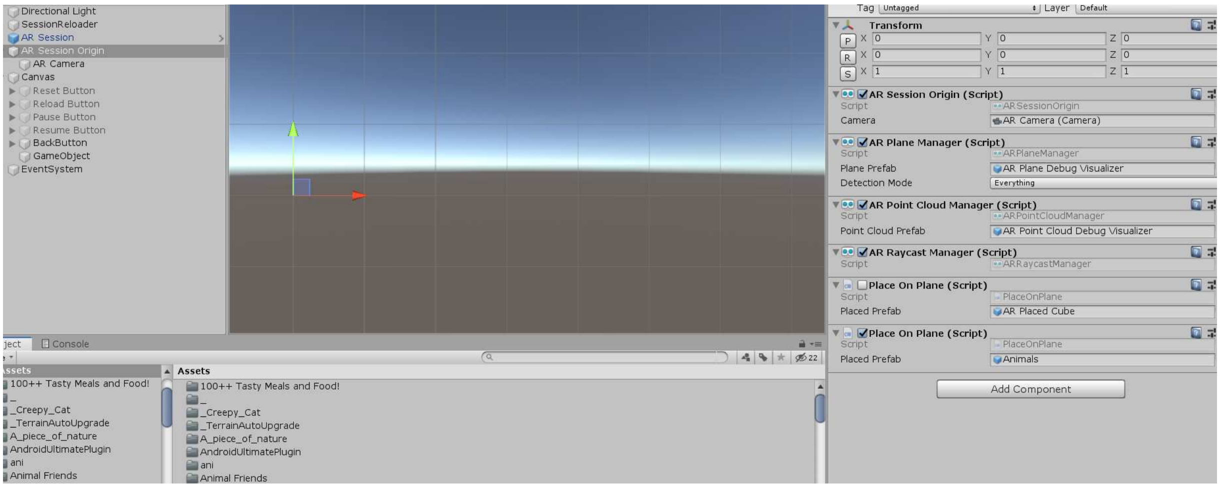

Figure 2.14 Implementation of AR pet-based interface in Unity.

Figure 2.15 The structure of each user includes a 3D avatar, user name, level, and the invisible 3D crown on the pet's head.

.

2.5 Evaluation

2.5.1 Purpose

To evaluate the gamified point system, I conducted an online shopping simulation experiment. The purpose of this experiment was to study whether AR-based 3D pet competition design has advantages compared to 2D-based and text-based competition design on user behavior and user experience.

2.5.2 Hypotheses

My main target using gamification is for promoting value creation (i.e., missions). In addition, I also examined gamification in promoting purchases and system usage. In the experiment, I look forward to exploring the impact of my system on value creation, user purchases, and system use. Therefore, I tried to understand and verify the following assumptions:

Hypothesis 1 (H1). *Compared with 2D- and text-based design, AR-based 3D pet design motivates participants to complete more missions.*

Hypothesis 2 (H2). *Compared with 2D- and text-based design, AR-based 3D pet design increases participants' website browsing and product purchases.*

Hypothesis 3 (H3). *Compared with 2D- and text-based design, participants prefer to use the gamified point system based on AR-based 3D pet design.*

2.5.3 Participants

Twelve volunteers (eight of which were female) that included eight laboratory students, between the ages of 20 and 27 (M = 23.4) participated in this experiment. All participants had experience using the traditional point system. All participants reported having played at least one multiplayer video game before. Participants were not informed of the purpose of this experiment.

2.5.4 Conditions and Procedure

Task

The task of each shopping experiment is that the user can choose the goods needed for lunch with some conditions when shopping. The user chooses among all the products on the shopping website. The quantity of each product can be more than one. Users can freely choose products, but they must buy something for lunch. For each purchase of a product with a special attribute, the number of missions completed can increase by one.

Shopping site description

There were 180 products on the shopping site, which were divided into 14 categories. The number of products in each category was 5–19. Among the 180 products, there were a total of 15 healthy foods, 15 local products, and 19 environmentally friendly products. The prices of all commodities are relatively close. This eliminates the impact of price differences as much as possible.

Healthy food was a separate category included in 14 categories, and environmentally friendly products were also classified as a separate category included in 14 categories. The local products carried the word "Fukuoka" in their names. To complete a mission, users needed to choose the corresponding category (environment-friendly, local, or healthy). Each mission could be completed multiple times.

Taking the existing shopping website as a reference, I designed the structure of the shopping website for the experiment. The website has a 3-level structure. Level 1 shows all the categories. Level 2 shows the products with names inside each category. Level 3 shows detailed information about the product (see Figure 2.16). When the user clicks the button on the main interface of the system, the level 1 page will be displayed. In the second line of the level 1 page, the first category is healthy food, and the second category is environmentally friendly products. After entering the level 2 page, the user can see all the products in this category. Products with Fukuoka in the name on the level 2 page are local products. If the user wants to further view the specific information of the product, he can enter the level 3 page. In order to facilitate the experiment, I built the link to the shopping website into the gamified point system.

Figure 2.16 The three-level structure of shopping websites.

Conditions

There were 3 conditions in the experiment. In **condition 1**, users conducted online shopping experiments using the gamified point system with leaderboard (**c1**). In **condition 2**, the gamified point system with 2D pet portrait was used (**c2**). In **condition 3**, users used the gamified point system with 3D pet (**c3**).

In the three conditions, the shopping website and the mission interface remain the same. The only difference between the three conditions is the competition interface. The competition interface will be displayed in the form of text, 2D and AR-based 3D characters in **c1**, **c2** and **c3**. In **c1** and **c2**, the text-based and 2D-based display were automatically displayed after the participants clicked the button linked to the competition interface, without their additional operations. In **c3**, after clicking the button, the participant needed to scan the plane through the mobile camera and selected the placement position to instantiate the 3D pets. All 3D pets were displayed at the same time after selecting the placement location.

Procedure

Order of sequences

In order to conduct the study, 12 participants were randomly divided into 3 groups of 4 people in each group. Each experimenter performed 3 conditions every day for 3 days with Latin Squares design [48]. Users made purchases from all products in every condition. The users in the first group conducted the three-day experiment in the order of sequences 1, 2, and 3. The users in the second group conducted a three-day experiment in the order of sequences 2, 3, and 1. The users in the third group conducted a three-day experiment in the order of sequences 3, 1, and 2. One sequence represents the shopping experiments in one day. Between the three conditions in one sequence, the participants were given half an hour to take a break.

Training

All participants were given instructions on the experiment before each condition. The instruction included the introduction of the system, the shopping website, and the shopping operation process. The system introduction included the introduction of each interface, the association between the interfaces, and how to use each interface. The introduction of shopping websites mainly includes the structure of the website and product information. The shopping operation process includes browsing the mission content before online shopping, conducting online shopping, browsing the number of completed missions, and participating in the competition after shopping. In addition, participants were told how to complete the mission, and completing a mission can raise the level in the competition. Purchasing health food products, environmentally friendly products, and choosing products with Fukuoka in the name were considered to complete the mission. The completed quantity of missions can be added up. After that, a researcher conducted a complete simulation experiment demonstration to show how to use the system for online shopping. Participants were allowed to experience the system and freely ask questions. A researcher acted as an instructor, answering participants' questions and helping them to familiarize themselves with the system, shopping website, and experimental process.

Experiment

The experiment began after the participants reported that they have mastered and understood the content and system of the experiment. During the experiment, a researcher was present to help solve possible problems in the experiment and help participants complete the experiment successfully without subjectively affecting the experiment. At the end of each experiment, the researcher confirmed the participant's shopping situation and entered the appropriate data into the database to update the participant's level state. Under all conditions, participants were free to choose products, and there was no mandatory requirement for the completion of a mission. There was no mandatory requirement for the time to use each interface.

After all experiments were completed, the participants were asked to fill out a questionnaire. The questionnaire has 3 questions and these questions use the 5-point Likert scale.

Data analysis

Google Analytics was used to record user behavior data during online shopping experiments, including average session duration [49], pages per session [49], items purchased, and their quantity. The timer in Unity was activated to record the usage time of each function of the system in each condition.

In this experiment, since commodity prices are relatively close, I mainly focus on the number of products purchased instead of the total price of the purchased products.

2.5.5 Results

(1) Mission Completion

I counted the number of missions completed in the experiment (see Figure 2.17). In condition 1, each user completed an average of 7.7 missions in one session (SD = 2.47). In condition 2, each user completed an average of 8.3 missions in one session (SD = 2.84). In condition 3, each user completed an average of 9.8 missions in one session (SD = 2.22).

I used the within-subjects ANOVA to compare three conditions. The results showed that the different competition design led to a significant difference in the number of missions between three conditions (F = 4.61, p = 0.01). Pairwise comparisons using the Bonferroni method [50] revealed that the difference between condition 1 and condition 3 is significant (p <0.05). H1 has been verified.

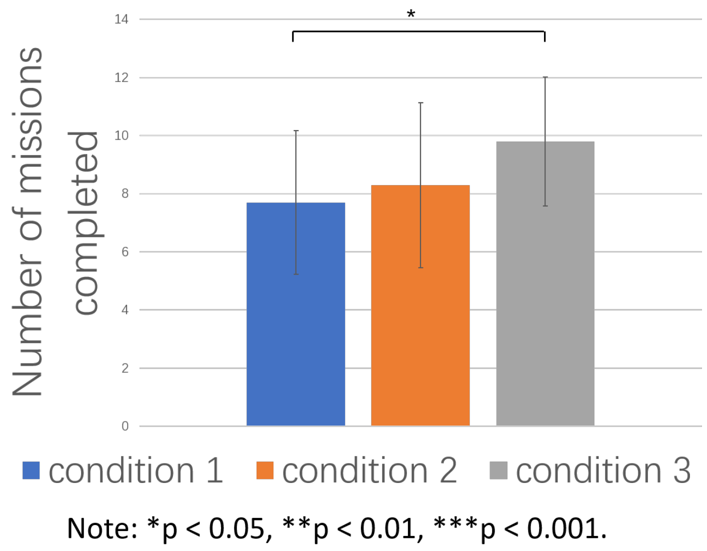

Figure 2.17 Average the number of missions per person per session.

(2) Online Shopping Engagement

(2-1) Pages per Session:

For web browsing behavior, I consider page views per session as an indicator. One way of measuring interest in the content is pages per session. From a business perspective, the higher the pages per session metric, the better [49]. I counted the number of pages per session [51] in three conditions.

In condition 1, the average pages per session per person was 35.7 (SD = 24.78); in condition 2, the average pages per session per person was 34.7 (SD = 20.19); and, in condition 3, the average pages per session per person was 39.5 (SD = 29.77).

I used the within-subjects ANOVA to compare the pages per session per person between three conditions. The results showed that the different competition design did not cause a significant difference in the average number of pages per session in the three conditions ($F = 1.20$, $p = 0.31$).

(2-2) Number of Purchases:

I counted the number of items purchased under the experimental condition. The number of purchases in the three conditions were recorded.

In condition 1, each user selected an average of 18.4 items in one session (SD = 6.83); in condition 2, the number was 18.9 (SD = 6.95); and, in condition 3, the number was 19.8 (SD = 6.50).

I performed the within-subjects ANOVA between three conditions. The results showed that there was no significant difference between three conditions (F = 1.27, p = 0.29).

Since neither the web browsing behavior nor the user's shopping behavior after browsing the Internet has been observed to change significantly, I cannot find evidence to support H2.

(3) System Usage

(3-1) Time:

I recorded the usage duration of the competition interfaces in three conditions. I use the time from entering the competition interface to exiting the interface as the duration of the competition interface in text-based and 2D-based design, while the time from when the user chooses the place to exiting the interface is considered as the duration of the competition interface in the AR-based 3D pet design.

In condition 1, each user used competition interface for 8.57 s on average in one session (SD = 4.96); under condition 2, the number was 11.25 s (SD = 6.78) for competition interface; under condition 3, the number was 44.96 s (SD = 32.75) for competition interface.

I performed the within-subjects ANOVA in competition interface between three conditions. There were significant differences in the competition interface between three conditions (F = 38.3, p = 7.3E-12) (see Figure 2.18). Pairwise comparisons using the Bonferroni method revealed that the difference between condition 3 and condition 1 is significant (p <0.001), as well as the difference between condition 3 and condition 2 (p <0.001). Moreover, significant difference was found between condition 1 and condition 2 (p <0.05).

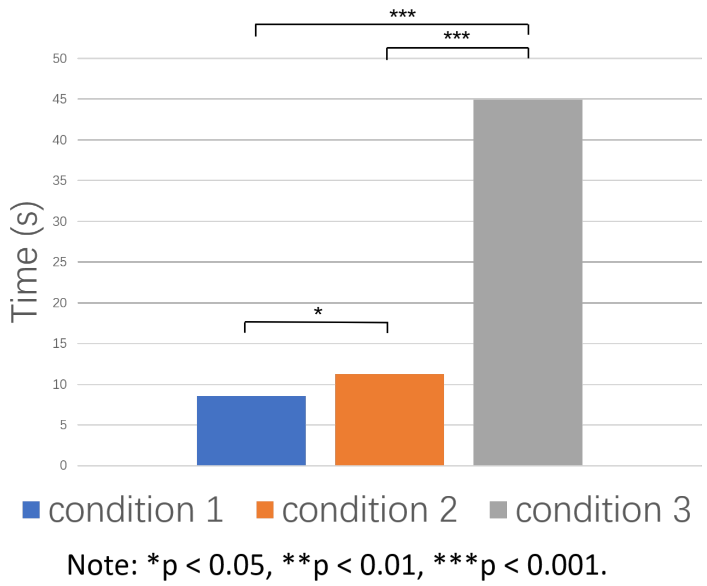

Figure 2.18 Average usage time of competition interface per person per session.

(3-2) Questionnaire Responses:

Question 1 was to understand the user willingness to use the gamified point system. The average score of question 1 is 2.75 for condition 1, 3.50 for condition 2, and 4.67 for condition 3. The results showed that users prefer using the competition with AR-based 3D pets. Question 2 was used to test the attractiveness of the gamified point system. The average score of question 2 is 2.83 for condition 1, 3.50 for condition 2, and 4.42 for condition 3. The results indicated that users think that the AR-based 3D pet is more attractive than text- and 2D-based design. Question 3 was used to understand which competition design users think is more motivating. The average score of question 3 is 3.08 for condition 1, 3.42 for condition 2, and 4.58 for condition 3. This means that the design of AR-based 3D pet design is more motivating. Based on the usage time and user questionnaire, H3 has been verified.

2.5.6 Comments From Experimenters

At the end of the user study, I asked the participant to comment on the experiment or systems.

Here are some responses: "I think the 3D pet system is the most attractive. It would be more interesting if you can have more interactions with pets." (P1/M); "Plane recognition needs to be more sensitive, which will improve the user experience." (P2/F); "The system with a pet makes the ranking more intuitive and interesting. Being able to compare with friends in a fun way inspires me to improve my ranking. This guides me to a certain extent, and I prefer to buy specific products." (P3/F); "The system provides a competition mode to encourage a user to do some purchase. Personally, I think using an AR avatar to show the user information is most interesting and attractive. In the AR avatar mode, I spent lots of time on my avatar and bought many healthy foods to make the avatar level up. I think it really encouraged me to purchase more healthy and eco-friendly products." (P4/M); "The system is easy to understand and use, and it can promote my competition awareness. The attractiveness of shopping in real life may be more reflected in the discount." (P7/F); "I hope to increase the interaction with 3D pets. It would be good if the system can give some hints about which product can speed up the growth of pets. I also want to buy some toys to interact with pets." (P8/F); "It would be interesting if 3D pet level and shape will change with the points. I feel that the competition system can promote my desire to buy." (P9/F); "I hope that 3D pets will unlock more forms or actions when they are ranked first." (P10/M); "It is quite interesting to include competition mechanism which may strongly promote the desire to consume. In the experimental stage, the total number of users (or friends) is only 4 people, which makes the competition interface (the ranking page) of these three systems can display in a good manner. However, when the total users increase to hundreds or thousands, how will the system display these rankings? It should be considered. The characters in the system are cute. It will be better if users can design their own characters. The following consideration is about privacy. If a friend and I know each other in both system and the real world, the ranking may expose our consumer behaviors or habits. Perhaps many users are not willing to tell other people how fast they are spending money." (P11/M); "The competition system will be more attractive if the people with the highest level could get a reward." (P12/F).

2.6 Summary

In this research, I proposed an AR-based 3D pet competition design on the mobile point system and compared different competition designs through an online shopping experiment. Through my experiment, I found that when users use the system with AR-based 3D pet competition design, users were encouraged to complete more missions and users agreed that the AR-based 3D pet design was more interesting and they were more willing to use it through user questionnaires. I believe that AR-based 3D pets have certain advantages in stimulating user behavior. My research can provide some inspiration for designers to design gamification systems.

Chapter 3

Exploring Gamification in a Marker-Based AR Framework

3.1 Background

Loyalty programs are structured marketing strategies, designed by merchants to encourage people to continue to shop at or use the services of businesses associated with the program [52]. They are effective at retaining customers by preventing them from turning to competitors and can also maximize the lifetime value of a customer by offering incentives to spend more and buy more often [53, 54, 55, 56, 57]. Successful customer loyalty programs are win-win for brands and consumers [58, 53].

Loyalty marketing began long ago, with the use of paper cards which graduated into plastic card-based systems [59, 60]. A point system is the most common loyalty program methodology [61]. Businesses issue physical point cards to their loyal customers, in order to encourage them to make repeated purchases and earn rewards points through the point system [62, 63, 64]. These points can be redeemed for a discount or a special offer later. However, in plastic card-based systems, interaction with the system is usually very limited [65]. Stamp card-based loyalty programs make use of paper cards that need to be stamped every time a customer makes a purchase, such that users can easily check the progress of stamp accumulation. The problem is that stamp card-based loyalty programs lack support for customer data analysis, which means that marketing and rewards cannot be targeted [66, 67, 68].

As consumers began to embrace mobile devices and social media, it became increasingly important for merchants to effectively incorporate smartphones into loyalty programs [69, 70]. A very important feature is that smartphone-based loyalty systems can easily meet the social needs of users, which can solve the problem that plastic-card based loyalty programs or stamp cards cannot facilitate linkage to social channels [69, 68]. Furthermore, smartphone-based AR applications provide users with new experiences that provide perception beyond the real world. With the help of advanced AR technologies, information about the surrounding real world of the user becomes interactive and digitally manipulated [71]. In addition, using gamification to establish an emotional connection between consumers and merchants has been considered as a fascinating and innovative marketing tactic [72, 73, 74, 75]. The idea is to add game elements to the loyalty program, in order to engage customers and encourage them to participate. Essentially, it is an opportunity to create a memorable customer experience and strengthen their emotional connection [76].

I consider solving the following deficiencies: (1) uncertain user–system connection. A loyalty program rewards the consumption of users through financial incentives, but rarely considers their motivation and emotional needs; (2) insufficient social connection. The main social loyalty actions include referring friends and sharing a brand or product with friends through social media. However, these actions are only one-time sharing activities and cannot facilitate long-term social connections. Furthermore, social media and loyalty programs are not tightly coupled, which may weaken the impact of social connection.

In this research, I explore a novel approach to integrate gamification and social interaction into a point system based on marker-based AR to solve these problems. The gamification part is a supplement to the current point system structure. My methodology includes: (1) using gamification to create mission frameworks that satisfy the motivations of different users and to build emotional connections between users and the system with a pet-based design. New input (i.e., mission) is added into the gamified point system. Users can complete the mission according to their own preferences. To reward the completion of a mission, new feedback is designed as a reward, including value points, pets, and virtual food. The user gets value points and upgrades the level after completing the mission. Value points can be used to purchase virtual food and help pets recover energy in the system. In the end, the income, expenditure, and feeding of the pet create a positive cycle. The desire to take care of a virtual pet may facilitate and sustain the motivation for using the system, which can establish an emotional connection between the user and the system; (2) Social impact is tightly coupled into the point system to establish long-term connections between users. Based on these game elements, the system provides channels for interpersonal communication (i.e., competitive and non-competitive interactions), which allows users to engage in long-term interactions without binding social media. Users can interact with each other by competing with pets or giving away virtual food in this system. I performed two experiments to examine the effects of game elements and social cues. In the first experiment, I analyze the change in online shopping behavior before and after adding game elements. In the second experiment, I study the effects of social cues by using the same game elements.

I introduce the detailed system design and implementation of the gamified point system. Mobile devices and a physical point card are used together. The physical point card is used as a pattern in a marker-based AR system and game elements will be superimposed onto the card, allowing users to interact with pets. A physical point card is used to identify the cardholder as a participant in the program [60]. I evaluate the system to explore how game designs influence user behavior and the impact of social cues on system usage. I believe that my research provides inspiration for the design of gamified systems and their potential applications.

3.2 Relationship Between Chapter 2 and Chapter 3

Chapter 2 and Chapter 3 have certain connections and some differences (see Figure 3.1). Chapters 2 and 3 both combine gamification design into the AR framework to provide a new system framework in the context of the point system. But the two chapters are different in the dimension of exploration. Chapter 2 explores the impact of different designs in competition on users' online shopping behavior, as shown on the Y-axis in the figure. In chapter 3, I explore the influence of different game elements in constructing the system framework, as shown on the X-axis. I add missions and AR single-user interactions in the point system to understand the impact of missions and AR single-user interaction, and then add two multi-user interaction methods to study the advantages of multi-user interaction. Although I used a pet-based design in both chapters, there are still some differences between them. In Chapter 2, pets are the avatars of users. The system allows users to participate in competitive interaction through a sense of substitution. In Chapter 3, pets encourage users to actively use the system by stimulating their caring desires.

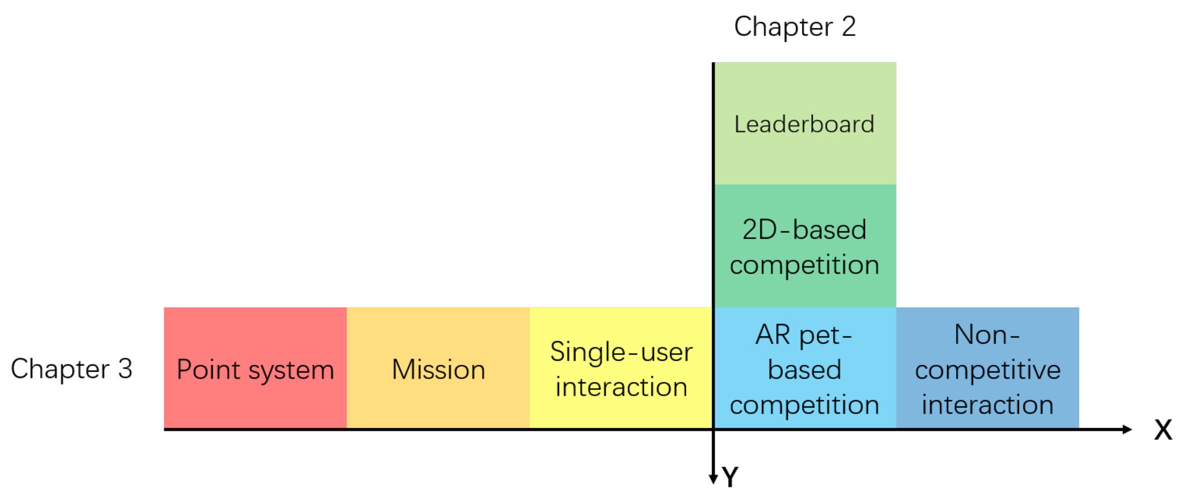

Figure 3.1 Relationship between Chapter 2 and Chapter 3.

3.3 Related Work

Many loyalty system designs are proposed to engage users. In this section, I describe the related works in detail and their limitations, also the advantage of my proposed method with the works. In order to design a gamified loyalty system, I consider combining social incentives, marker-based AR, and AR games. The relationship between the related work and my proposal is shown in Figure 3.2.

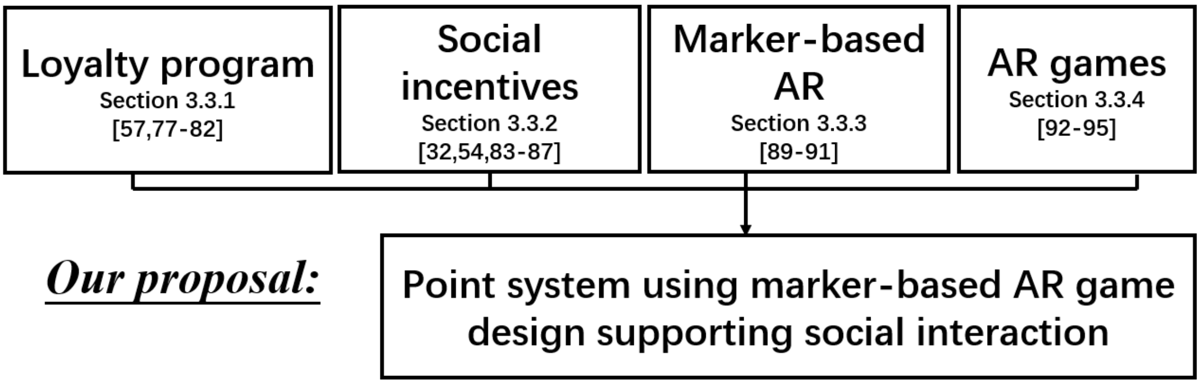

Figure 3.2 The relationship between the related work and my proposal.

3.3.1 Loyalty Program

Loyalty programs provide an interesting possibility for vendors in customer relationship management. To provide more attractive loyalty programs, different system designs have been proposed from different aspects (e.g., privacy-enhanced scheme [57], NFC scheme [77, 78], and big data analysis [79]).

Enzmann et al. present two variants of a privacy-friendly loyalty system [57]. It intended to increase user participation by protecting user privacy. However, solving privacy issues is usually not the main issue of the loyalty systems. I need more general solutions to attract user participation.

The design of a new way of NFC-enabled loyalty system was proposed to solve the problem of too many loyalty cards [77, 78]. This solution can be implemented in conjunction with users' mobile devices, thus providing convenience for users. This hardware enhancement solution provides convenience when users participate in multiple loyalty programs. But there is not much benefit when users use a certain loyalty system alone.

Galletta et al. proposed cloud-based software as a service architecture that stores and analyses big data related to purchases and products' ranks in order to provide customers a list of recommended products [79]. Although providing better recommendation results may help users to better select products, users will often ignore the recommendation notice.

Different from the above-mentioned loyalty system designs, I designed the system from the perspective of gamification to provide a gamified context for users.

The theoretical idea of gamification combined with loyalty programs was proposed and analyzed from a business perspective [80, 81, 82]. However, how to combine gamification to design a loyalty program framework is still to be explored. Unlike the theoretical model analysis, I focus on applying game elements to construct a system framework.

3.3.2 Social Incentives

Social incentives concern a broad range of interpersonal rewards and motivations that encourage people to behave in a socially valued and approved manner [83]. Social incentives include projecting a positive social image and reputation, gaining social acceptance, and gaining a better place in the social hierarchy.

The main social incentives include competition and collaboration [84, 85, 86]. The elements of competition and collaboration were proved to help sustain the crowd's motivation to participate [87].

Many studies have shown that competition increases a player's level of engagement. Li et al. designed a multiplayer software tutorial system called CADament [32]. Their study showed that their system resulted in better performance over pre-authored tutorials by improving learner performance, increasing motivation, and stimulating knowledge transfer. I intend to introduce competition into the system design to increase user participation.

Meanwhile, some studies have found that competition may become a negative factor if players find themselves at the bottom of the competition [88]. Competition as a social method will drive users to show better performance, but it may also make some users feel uncomfortable. Therefore, I consider providing users with more social interaction choices in addition to the competition.

Previous research found that sharing rewards greatly increases the experiential and social value that users may derive from participating in a loyalty program [54]. But the current point system lacks channels for users to share rewards. Therefore, sharing is considered as another design of non-competitive interaction between users in the system. In summary, my research mainly explores the impact of social incentives from two different aspects of interactions: competition and sharing.

3.3.3 Marker-based AR

A marker-based AR looks for a specific image pattern in the environment and superimposes the virtual object on top of it. The camera of the AR devices will continuously scan for input and perform image pattern recognition and allow users to place virtual objects.

Norraji et al. [89] discussed a type of mixed-reality book experience that augments a coloring book with user-manipulated three-dimensional contents in a mobile-based environment. But the user had limited interaction with the AR marker. AR markers were only used to display virtual objects.

Bouaziz et al. [90] proposed a learning system based on AR that overlays digital objects on top of physical cards and renders them as 3D objects on mobile devices to help with teaching food skills using related phrases and sounds. It still lacked user interaction with virtual objects. Moreover, the system lacked interaction between users.

Akussah et al. [91] developed a marker-based handheld AR application for learning geometry with a focus on the individual's experience, then expanded it into a collaborative AR game that addresses other mathematical learning outcomes. This research mainly focuses on the use of AR markers as a carrier for information display. My research is to use an AR marker as the user's identity in the system to interact with the system and with other users.

3.3.4 AR Games

AR games are the real-time integration of game visual and audio content with the user environment. AR gaming expands the playing field, taking advantage of the diversity of the real-world environment to keep the games interesting.

Previous studies have found that AR-based feedback can stimulate the interest of game users and provide users with new experiences [92]. Combining the characteristics of AR games as dynamic feedback may bring advantages to the gamified system design.

Pokémon GO, considered the breakthrough AR app for gaming, uses a smartphone's camera, gyroscope, clock and GPS and to enable a location-based augmented reality environment [93]. It uses the mobile device's GPS to locate, capture, battle, and train virtual creatures, called Pokémon, which appear as if they are in the player's real-world location. This design of combining AR virtual pets and the real world provides a reference for the AR pet-based design in the system.

However, Pokémon GO's location-based AR design method is more in line with the gamified system design related to exercise themes. Considering the usage scenarios of the gamified point system, I use marker-based AR instead of location-based AR in the system.

Allen et al. [94] showed their workflow in making a 3D virtual pet game, starting from completing the concept, making 3D models, scripting, and integrating AR as the main feature to provide a unique experience in simulating a pet-raising scenario on a mobile device. Their study provides a reference for how to build a virtual pet game. But their work is mainly to build 3D pet models and simulate a pet-raising scenario.

My research uses a similar approach that combines pet-raising games with a point system. The difference is that in the system, I not only pay attention to the raising scenes of pets, but also pay attention to the social design between users.

When designing AR games, some design guidelines need to be considered to provide guidance for the system design. Wetzel et al. [95] presented a set of design guidelines for designing AR games, drawn from the experiences of three mixed reality games. These guidelines provide specific guidance on relationships between real and virtual space, social interactions, the use of AR technologies, and maintaining consistent themes. Some guidelines, such as "stick to the theme" and "keep it simple" gave us some instruction in my design. I designed the single-user environment and multi-user environment of the gamified point system in accordance with the guidelines.

3.4 System Description

The system features an AR pet (i.e., an animal companion), with the aim of evoking the caring nature of users. The gamified point system provides an interchange between shopping in the real world and pet-raising in the virtual world.

3.4.1 Single-User Interaction

In the single-user interaction (see Figure 3.3), the solid line represents the traditional point system structure. After shopping, customers get points as feedback for shopping. The gamified point system adds the design of game elements (dotted lines) to the traditional point system structure. Users can browse the mission of value creation during shopping. A value point provides feedback after completing a mission in shopping and can be used to redeem virtual food. Virtual food can then be used to feed the pet. The pet is the core of design and is used as a bridge between the user and the system.

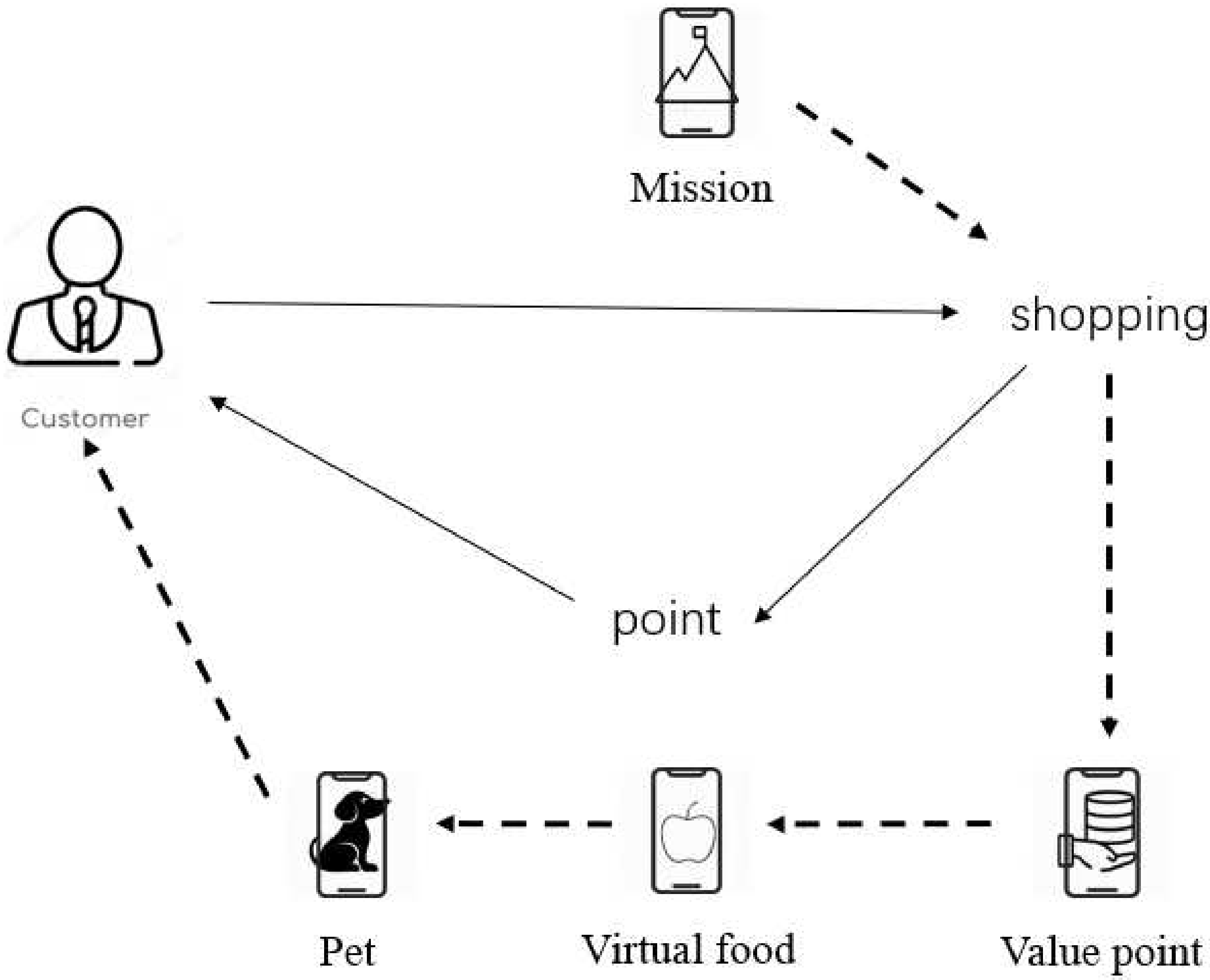

Figure 3.3 Single-user interaction.

Game Element—Feedback

(1) Pet

In the system, every user can feed a virtual pet. The pet reflects the user's status in the virtual environment. A pet has important attributes including level and energy. The level reflects the long-term status of the user and the energy is the feedback for the short-term participation. The pet gains an experience value (EXP) after a user completes a mission. If the EXP of the pet reaches a certain threshold, the pet will level up. Pets gradually lose energy. In order to keep the pet energetic, the user needs to feed the pet.

(2) Virtual Food

Virtual food is used to help pets recover energy and can be given to other users as a gift. The food given by others can also be used to restore the energy of the pet.

(3) Value Point

If the user has completed the mission, they can obtain value points after shopping. Value points can be used to purchase virtual food in the virtual environment.

After shopping, users can enter the value point and pet interface from the main interface. In the value point and pet interface, the user needs to point the phone camera at a physical card, in order to interact with the pet or to see the value points, as they will be superimposed onto the card (see Figure 3.4).

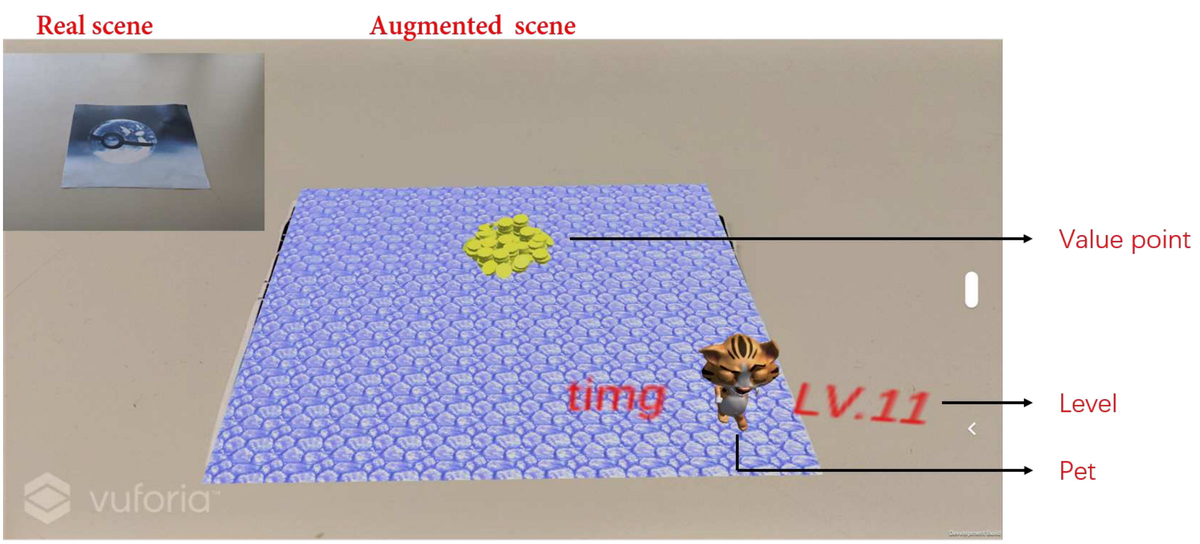

Figure 3.4 Value point and pet interface. The AR information is superimposed onto the physical point card.

The size of the value point will vary, depending on the quantity. The level and user name are displayed near the pet. The pet gradually loses energy and its movement changes accordingly, in order to remind the user to feed the pet.

If the user completes a mission, the value point increases. The user can click on value points to exchange for virtual food. After the exchange, the value points are consumed and decreased. Virtual food will be displayed around the value points. By clicking on the virtual food, it will be consumed and the pet will immediately recover a certain amount of energy and give action feedback accordingly.

Game Element—Mission

The mission aims to remind users of multi-value creation in shopping. Multi-value creation refers to the value that users create in shopping, such as environmental and social impacts. The mission was designed as traditional point systems only reward a user's consumption, rather than considering the user's purchase motivation. The main purpose of the mission is to encourage different purchase motivations to meet their needs, thereby promoting sustainable consumption and healthy living.

When the system is turned on, the system will display the main interface. The user can view the mission through the button linked to the mission interface on the main interface. In the mission interface, missions are displayed in text form. Users can browse the mission interface to view the content of the mission when shopping and view the number of the completed missions after shopping. In order to motivate users to complete the mission, I designed a virtual environment based on AR pet in the system. If users complete the mission, they will get feedback in the virtual environment. The content of the mission is set to be related to shopping, such as purchasing products that meet a certain requirement. When a user chooses to purchase a product that meets this requirement, the mission will be deemed completed. On the contrary, if there is no product that meets this requirement among the products purchased by the user, the mission is considered to have not been completed. Users can freely choose the mission they want to complete during shopping according to their preferences. If the mission is failed, users will not receive rewards.

3.4.2 Multi-User Interaction

Competitive Interaction

In a competitive interaction, users can compete with other users through their pets. I designed user interfaces for competitive interaction across the network. Users willing to participate in the competitive interaction will be included in a name list, which is considered to allow other users to access their level information. The user can view the name list of users and choose rivals to compete (see Figure 3.5). The pet with the highest level will wear a gold crown, while the pet with the second-highest level will have a silver crown, and the pet with the third-highest level will have a bronze crown. The design of competitive interaction is asynchronous. That is, when one user participates in the interaction, other users do not need to attend the interaction at the same time. According to the user's choice, the system will instantiate the pets of rivals to compete. It ensures that users can get feedback through competitive interaction at any time.

When the user enters the competitive interaction interface from the main interface, a room will be created, and the user's pet will be instantiated in the middle of the room automatically without manual control by the user. After that, the user can click the button in the upper right corner of the competitive interaction interface to browse the list of rivals. I adopt a continuous competition mode instead of a turn-based mode. Users can choose any number of rivals to compete. The maximum number of users participating in the competitive interaction includes the user and all rivals in the list. There is no limit to the number of rivals. In the current system, I set the number to four. The pets of the selected rivals will be automatically instantiated next to the user's pet. In the current competitive interaction, users who win the game will not get rewards, because I want to know whether the competitive interaction itself will bring internal motivation without external incentives such as point or value point.

Figure 3.5 Competitive interaction interface.

Non-Competitive Interaction

In the non-competitive interaction interface (see Figure 3.6), users can share their food with other users. The user can enter the non-competitive interaction interface from the main interface by clicking the button linked to the interface. The interface is very similar to the value point and pet interface. The user also clicks on the value points to purchase virtual food. However, when the virtual food is clicked, the virtual food will not be consumed but a user list will pop up. The user can select the recipient of the gift from the name list and send the gift. After that, the food disappears. When the recipient uses the system and opens the non-competitive interaction interface, the recipient can see the virtual food displayed next to the pet. The recipient can choose to use it to feed the pet in the value point and pet interface or continue to give it to another user. Similar to the design of competitive interaction, users will not get additional rewards when they give the virtual food to other users, because I want to know whether non-competitive interaction itself will bring motivation. In my research, the main reason I separate this interface from the value point and the pet interface is that I want to study the difference between a single-user game environment and a multi-user environment. Therefore, in the actual deployment situation, the interface can be unified with the value point and pet interface, and various methods can be used to realize pet feeding and gift-giving functions. For example, long-pressing the selected food and dragging it to the pet will trigger the pet feeding function, and clicking on the food will pop up a name list to allow the user to give it away.

Figure 3.6 Non-competitive interaction interface. User timg gave an apple to user menghuan.

3.5 System Implementation

3.5.1 System Hardware

The main hardware devices used for the development of the prototype system included a laptop and smartphones. The laptop was used to build the system and works as a server. Smartphones were the mobile devices used to install the client. Windows 10 Home Edition was installed on the laptop. The processor was an Intel(R) Core(TM) i7-6500U CPU @2.50 GHz, and the laptop had 8 GB RAM.

3.5.2 Development Environment

The development software was Unity 2019.2.11f1 (64-bit), a cross-platform game engine [96]. Unity 3D was used to build and render the AR system. The Vuforia SDK was used for the AR implementation. I deployed an ARCamera into the scene and activated the target databases. I added five targets to the target database; that is, up to five users can use their own physical point card to use the gamified point system. Increasing the number of targets will allow more users to participate. Photon Unity Networking was used to implement the competitive interaction [97]. For the server, we deployed WampServer Version 3.0.6 32 bit, consisting of the Apache web server, OpenSSL for SSL support, and MySQL database. Apache and MySQL were kept running on the laptop.

3.5.3 Overall System Structure

To realize this multi-user system, I used the same system architecture as that in Chapter 2. Users can participate using a mobile device. Every user connected to the server constantly receives data, locally creating a representation of the game state. If a user performs an action, that information will be sent to the server. The server checks whether the information is correct, then updates its game state. After that, it propagates this information to all users. Communication between Unity 3D and MySQL was implemented in the PHP programming language. I used the WWW and WWWForm classes to send and receive requests between Unity and the server. When receiving from the database, the information was converted into JSON format and received. After receiving, it was decoded into a string format.

3.5.4 Interface Implementation

I have implemented five systems (see Figure 3.7). Each system contains different interfaces, and the system has built-in buttons to connect to the same shopping website. I will introduce the implementation of each interface in detail.

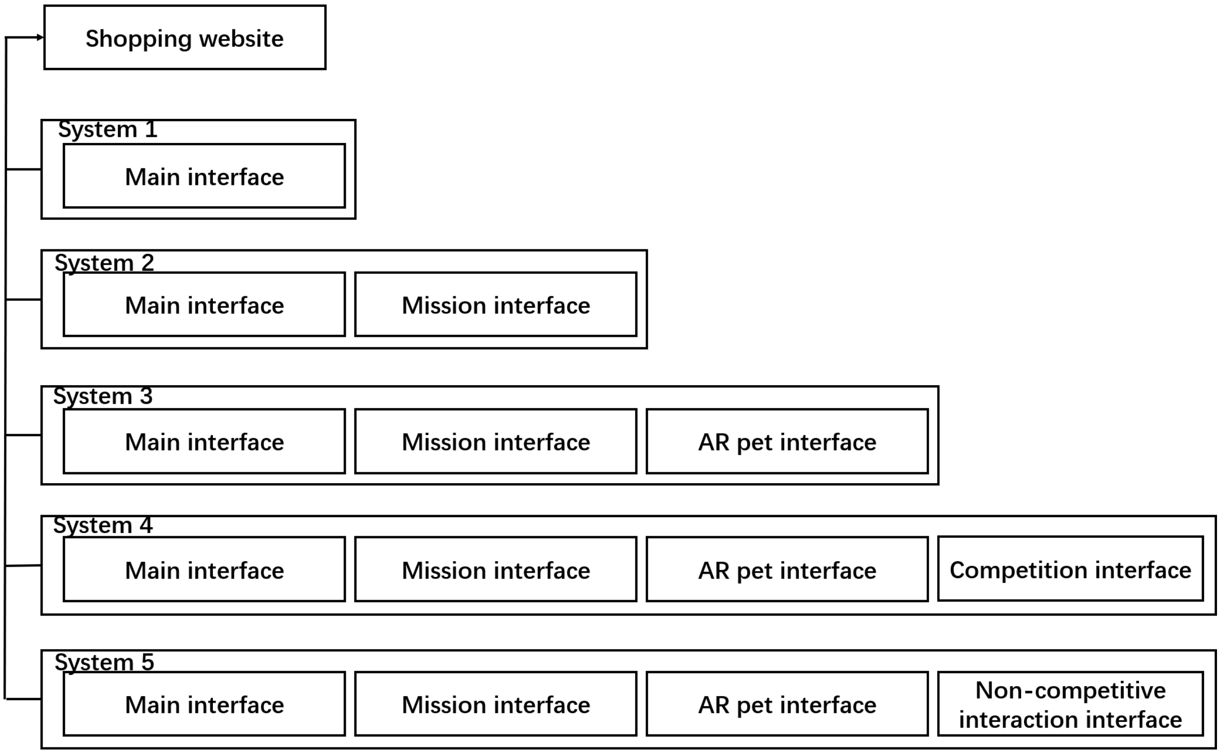

Figure 3.7 Five systems with each containing different functions.

Main Interface

The implementation of the system's main interface is divided into two parts, canvas, and background. In the background part, I used the same background pattern as the previous design. The canvas part contains different buttons corresponding to different functions (see Figure 3.8). The button on the left is the button to connect to the shopping website. The first button on the upper right side is connected to the mission interface, and the second button is connected to the AR pet interface. The third button is connected to the competition interface and the fourth button is connected to the non-competitive interactive interface. I have designed five systems, each of which corresponds to different conditions in the experiment. The main interfaces of the five systems have different buttons. In the main interface of each system, some buttons will be displayed while others will be hidden. The shopping page and the mission interface are the same in the five systems.

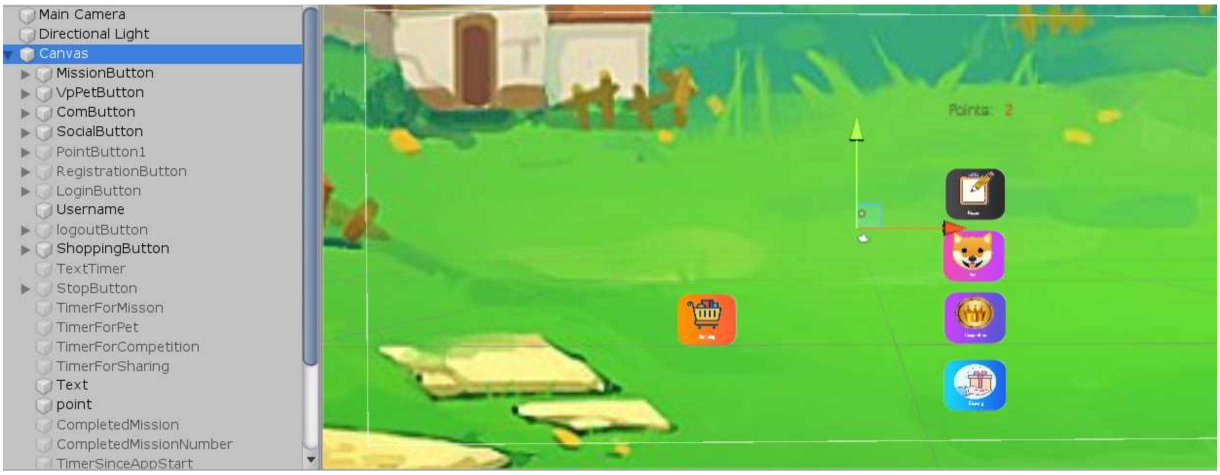

Figure 3.8 Canvas part of main interface. In the main interface of each system, some buttons will be displayed while others will be hidden.

Mission Interface

Figure 3.9 shows the implementation of the mission interface in Unity. The mission interface is mainly divided into two parts, one is the background element (see Figure 3.10), and the other part is the multiple text boxes on the canvas. Since I have designed three missions in the system, the three missions are arranged from top to bottom in the interface. The back button on the right allows the user to click to return to the system's main interface. The upper right corner consists of two text boxes, one is a fixed text box that displays completed missions, and the other is a text box that displays the number of completed missions returned from the database.

Figure 3.9 Implementation of mission interface in Unity.

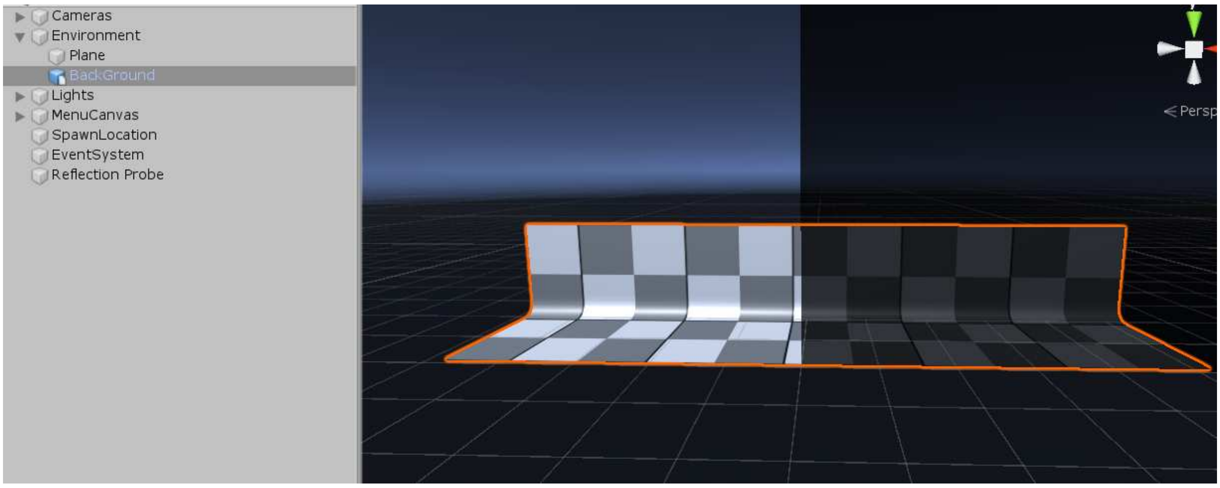

Figure 3.10 Background image of mission interface.

AR pet Interface

Figure 3.11 shows the implementation of the AR pet interface. The AR pet interface design consists of two parts, one is the canvas design, and the other is the AR card design based on image targets (see Figure 3.12). The back button allows the user to go back to the main interface of the system. The virtual food purchase column is usually invisible. When the user clicks on the value points, the script bound to the value points will be activated and the virtual food purchase column will become visible. The virtual food purchase column contains several virtual foods and purchase buttons. Users can consume value points and get virtual food by clicking the button. After clicking the button, the client will send a request according to the type of virtual food selected by the user. After the database accepts the request, the information in the database will be processed to modify the parameter value. The script bound to the object of the AR point card will continue to obtain the corresponding parameter value from the database and display it in the name and level box near the pet. The parameter values of the virtual food will also be obtained and determine whether the food models will be displayed or hidden. Pets will make different actions according to the level of energy to provide users with dynamic feedback.

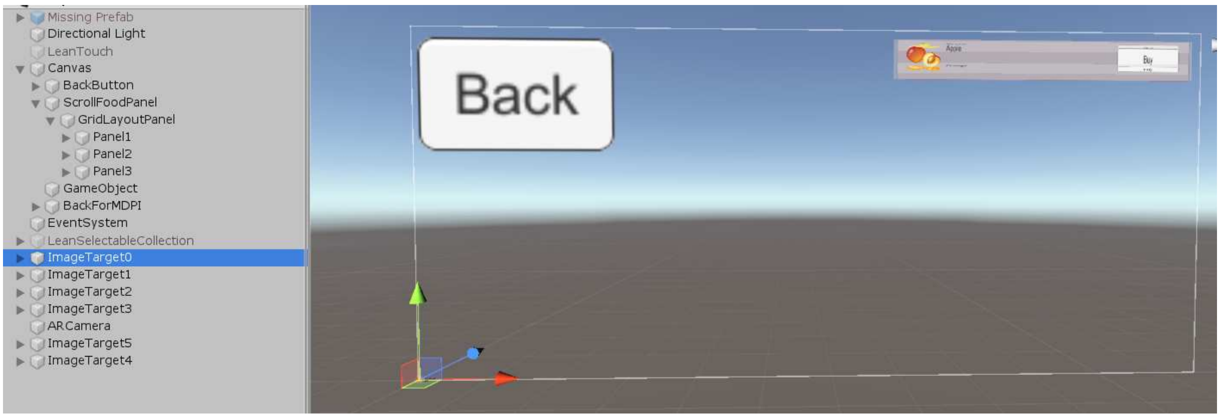

Figure 3.11 Implementation of AR pet interface in Unity.

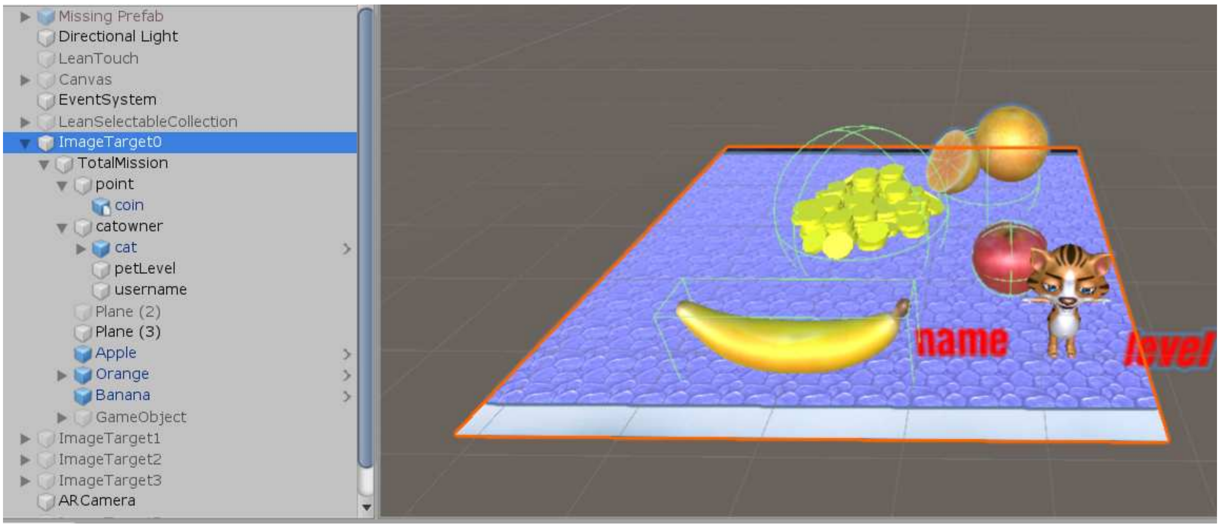

Figure 3.12 AR card design based on an image target.

Competition Interface

Figure 3.13 shows the implementation of the competition interface.

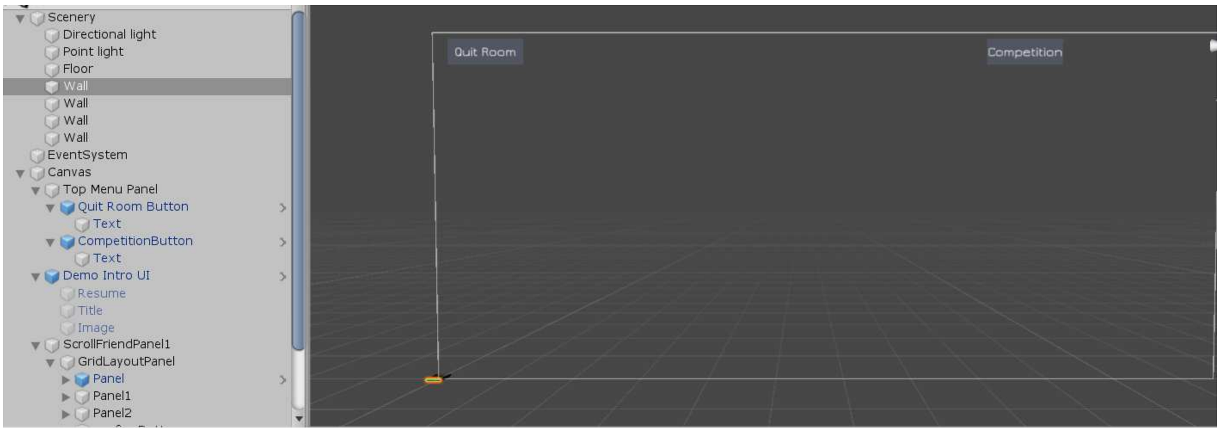

Figure 3.13 Implementation of competition interface in Unity.

Competition interface design includes two parts, one is canvas design, and the other is competition room design. Figure 3.14 shows the competition room in the scene. In the view of the main camera, the two parts will be merged as shown in Figure 3.15. When the system is running, the camera angle will be automatically adjusted to view the user's pet from the front. The quit room button allows the user to return to the main interface of the system. The competition button in the upper right corner is used to select the opponents to compete with. When the user clicks the competition button, a list of the user's friends will be displayed. The user can select several friends to instantiate their pets. After instantiation, the pets of the user and friends will be arranged from left to right. The data of users and friends will be obtained from the database and filled in the text boxes attached to the 3D pet models.

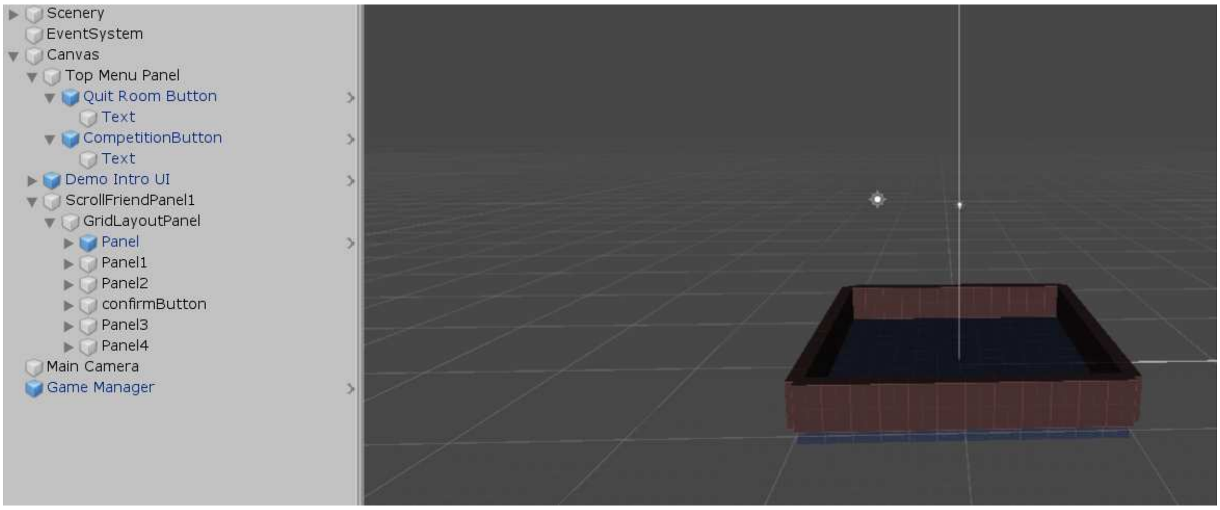

Figure 3.14 Competition room in the scene.

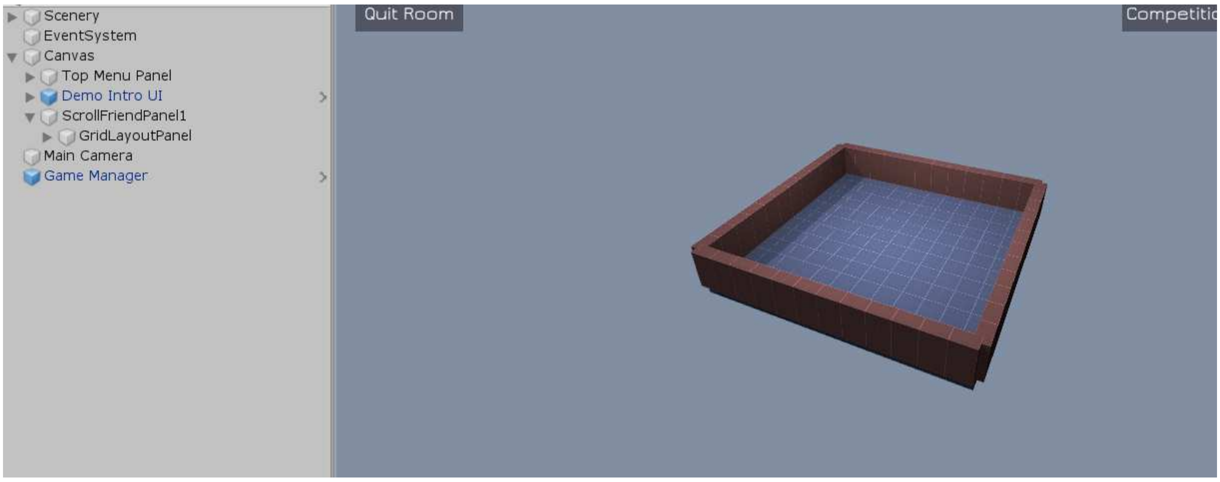

Figure 3.15 Competition room and canvas under the camera view.

Non-competitive Interface

Figure 3.16 shows the implementation of the non-competitive interactive interface. Non-competitive interactive interface design consists of two parts, one is canvas design, and the other is AR card design. The AR card design part is the same as that in AR pet interface design (see Figure 3.17). Virtual food models are attached with collision components to accept the click from users. In the canvas design, I added a user friend list column. It is usually invisible. When the user clicks on the virtual food, the script bound to the virtual food will visualize the user's friend list column. The user can click the button in the friend list column to select the person to receive the gift.

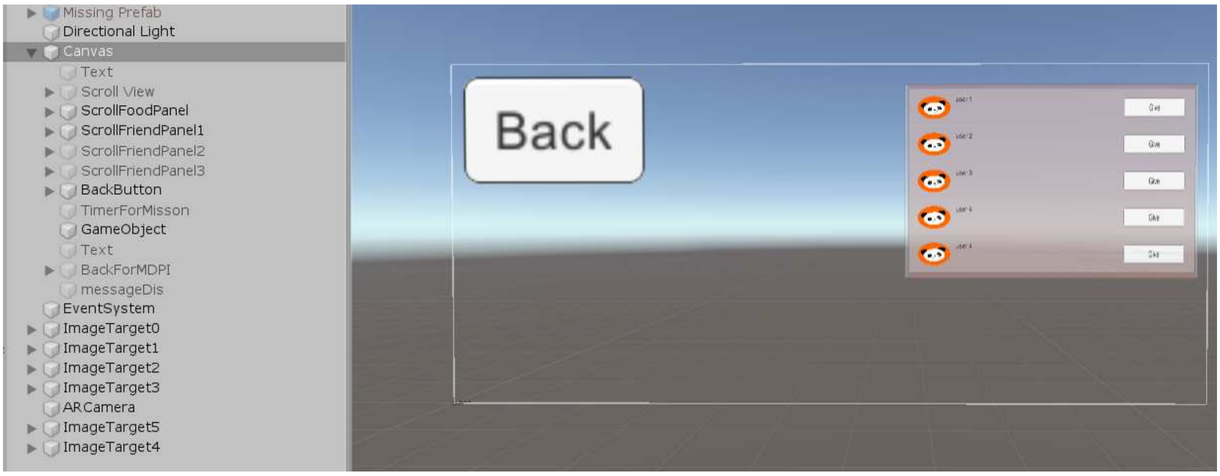

Figure 3.16 Implementation of non-competitive interaction interface in Unity (Canvas).

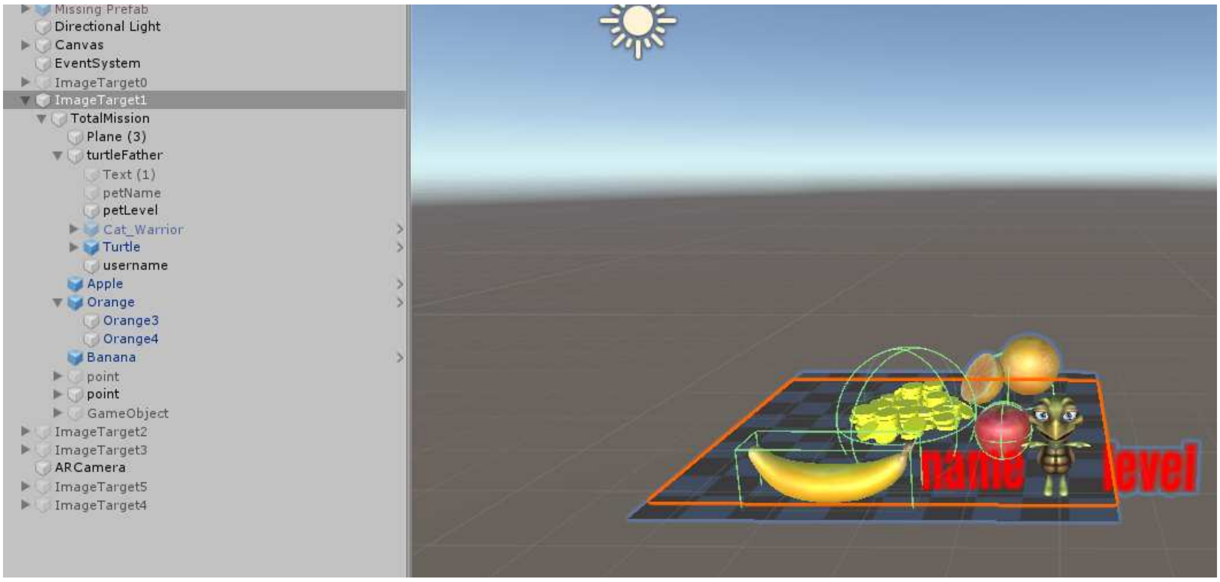

Figure 3.17 Implementation of non-competitive interaction interface in Unity (AR objects). AR card design for non-competitive interaction based on an image target.

3.6 Evaluation

My main goal of using gamification is to promote value creation. In addition, I have studied gamification to promote purchases and system usage. The system includes game elements and a multi-user environment. In Experiment 1, I explored whether game elements have an impact on value creation and whether game elements have an impact on users' purchases. In Experiment 2, I explored the impact of the multi-user environment on the use of the system. Combining two experiments, I explored the impact of the system on value creation, user purchases, and system usage.

3.6.1 Experiment 1

Purpose

To evaluate the gamified system, I conducted an online shopping simulation experiment using a within-subjects design. The purpose of this experiment was to study the effects of game elements on user shopping behavior.

Participants

Six student volunteers (three of which were female), including five laboratory students, between the ages of 20 and 26 participated in this experiment (M = 22.8). They were not informed in advance of the purpose of the experiment and the systems to be used. All participants had experience using the traditional point system (i.e., obtaining certain points after shopping) before the experiment. All participants reported having played at least one multiplayer video game before.

Shopping site description

Under all conditions, the structure and content of the website are the same. The structure and content of this website are the same as those in Chapter 2.

Task

The task of each shopping experiment is that the user can choose the goods needed for up to one day with some conditions when shopping. The user chooses among all the products on the shopping website. The quantity of each product can be more than one. Users can freely choose products they need for up to one day. Users can also choose to buy nothing while shopping. For each purchase of a product with a special attribute, the number of missions completed can increase by one. If there are multiple attributes, the completed missions can be accumulated.

Conditions

There were 3 conditions in experiment 1.

Condition 1 was to use the traditional point system for shopping. In the system, users can obtain a certain percentage of points according to the price of the purchased products. The user opened the shopping website to conduct a shopping experiment through the button built into the system and returned to the system to check the number of points after completing the shopping.

Condition 2 was to use a point system with mission and text information added for shopping (see Figure 3.18). Text information was a textual representation of the number of missions completed in the mission interface. The user viewed the mission before browsing the web for the shopping experiment and checked the number of completed missions and points after completing the shopping.

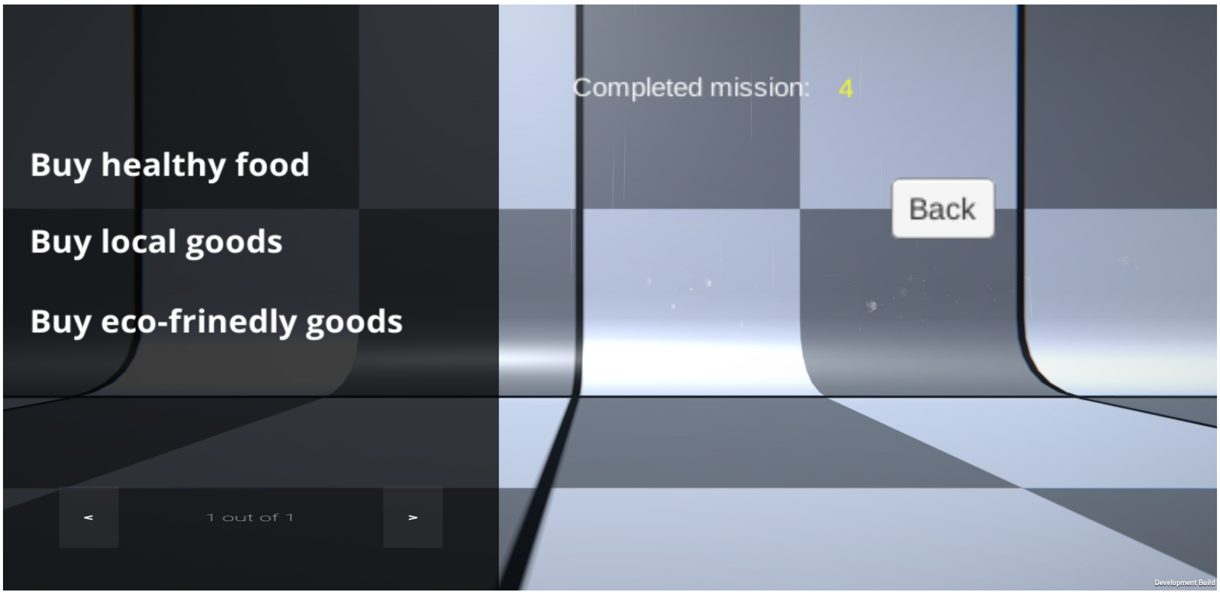

Figure 3.18 Mission and text information. The left side shows the daily mission, and the upper right corner shows the number of missions completed in text information.

Condition 3 was to use a gamified point system, which added mission and text (see Figure 3.18), as well as AR feedback (see Figure 3.4). Users can view the content of the mission before shopping. After shopping, users can check the number of points and completed missions in text form and gain game experience by interacting with AR feedback. The experiment was carried out in a controlled setting environment.

To sum up, the only difference between **condition 1** and **condition 2** was the mission and the text that showed the number of missions completed. The only difference between **condition 2** and **condition 3** was whether there was AR game feedback. Therefore, by comparing **condition 1** and **condition 2**, we can understand the impact of the mission on user shopping without AR-based feedback. By comparing **condition 2** and **condition 3**, we can understand the impact of AR-based feedback. I expect that feedback will be the main factor affecting user engagement.

Procedure

Training

All participants were given a brief introduction of the system for approximately 5 min and the basic operating procedures for approximately 10 min before each condition.The introduction includes instructions on the system and shopping website under experimental conditions. Then, the recorded video of using the system for shopping will be played to introduce how to use the system to do online shopping. After that, participants can use the system to experience it by themselves. At the scene, a researcher acted as an instructor, answering questions from participants and helping them to familiarize themselves with the system.

Experiment

To conduct the study, six participants performed three conditions, each for five days. In order to explore the impact of the gamified system on shopping, I added the shopping site to the experimental systems to facilitate users to conduct experiments. Therefore, users can easily find products that meet the mission requirement.

In the first five days, all users conducted online shopping experiments using the traditional point system (condition 1). After the purchase was completed, their points were updated. In the second five days, all users used the system with missions and textual information (condition 2). Pre-defined missions were designed, based on sustainable consumption [98] (i.e., the purchase of environmentally friendly goods, the purchase of healthy foods, and the purchase of local goods). To complete a mission, the users needed to choose the corresponding category (environment-friendly, local, or healthy). Each mission could be completed multiple times. The users could see how many missions had been completed through textual information. In the third five days, all users used the system with missions, textual information, and pet-based feedback (condition 3). The content and completion of the mission were the same as for condition 2. Under each condition, a researcher acted as a mentor to help the experimenters solve problems during the experiment. At the end of the daily experiment, the researcher confirmed the user's shopping situation and entered the appropriate data into the database to update the user's game state. Under all conditions, users were free to choose products, and there was no mandatory requirement for the completion of a mission.

Data analysis

Google Analytics was used to record user behavior data during online shopping experiments, including average session duration [49], pages per session [49], items purchased, and their quantity.

Results

(1) Mission Completion

I made comparisons of the number of missions completed (see Figure 3.19). In condition 1, each user completed an average of 19.2 missions in one session (SD = 7.7). In condition 2, each user completed an average of 26.4 missions in one session (SD = 9.6). In condition 3, each user completed an average of 33.2 missions in one session (SD = 10.1). Since users were free to choose products and there was no mandatory requirement for the completion of a mission, the increase in the number of items reflected the increase in user participation. Pairwise comparisons using the Bonferroni method revealed the significant difference between conditions 1 and 2 ($p < 0.005$), conditions 1 and 3 ($p < 0.001$) as well as conditions 2 and 3 ($p < 0.005$).

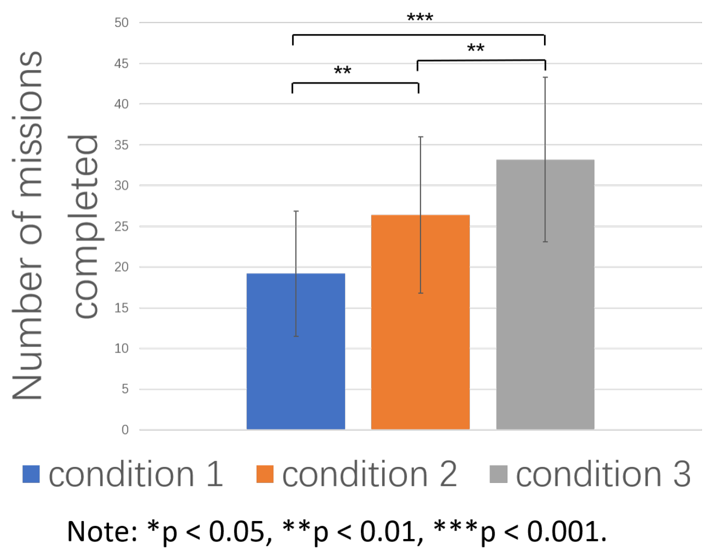

Figure 3.19 Average the number of missions per person per session.

(2) Online Shopping Engagement

Pages Per Session:

In the experiment, a session was one-day online shopping experiment. I calculated the number of pages per session [51] in the three conditions (see Figure 3.20). In condition 1, the average pages per session per person was 29.4 (SD = 10.5); in condition 2, the average pages per session per person was 41.1 (SD = 24.4); and, in condition 3, the average pages per session per person was 46.5 (SD = 27.7).

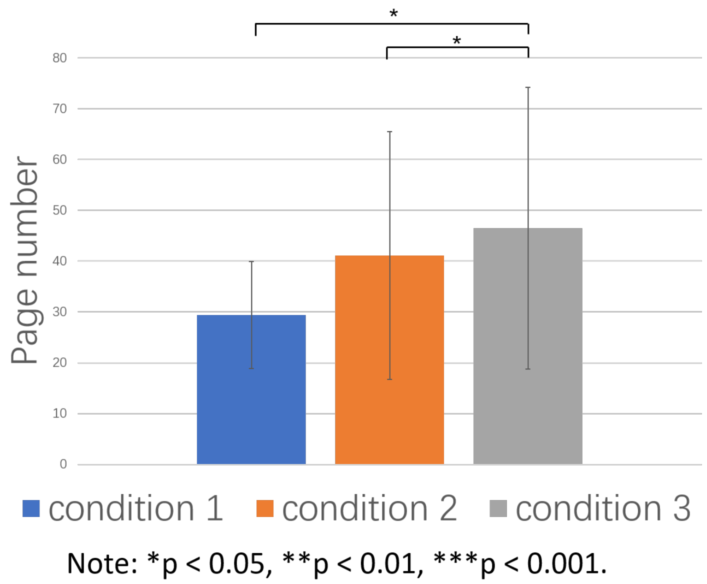

Figure 3.20 Average number of pages per session per person.

Pairwise comparisons using the Bonferroni method were used to compare the pages per session between every two conditions. The results showed that there was no significant difference in average pages per session between conditions 1 and 2 ($p = 0.06$). However, there were significant differences between conditions 2 and 3 ($p = 0.03$) as well as conditions 1 and 3 ($p = 0.02$). Since the structure and content of the website were consistent and users were free to complete mission and participate in the AR game, the increase in pages reflected the increase in user participation.

Number of Purchases:

The above indicator analyzes the participation of shopping websites. For shopping websites, in addition to website participation, user purchases are also an important indicator of online shopping participation. I learned in detail about the changes in user purchases in the three conditions.

The number of items selected in the three conditions was recorded (see Figure 3.21).

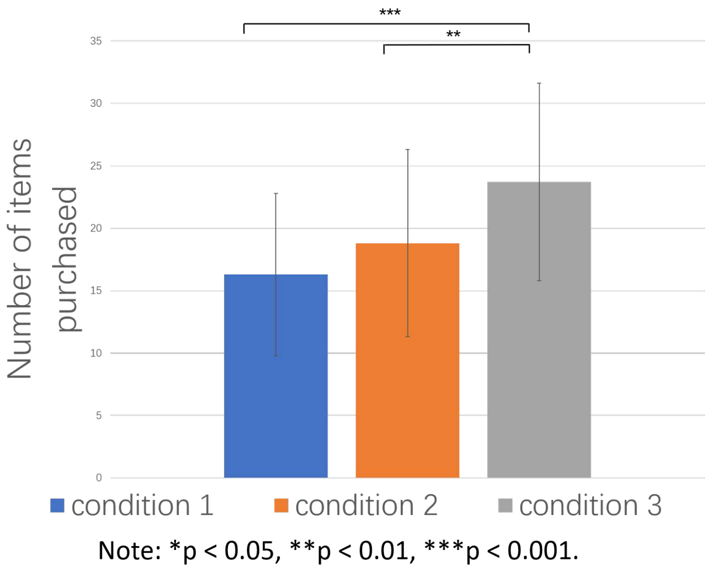

Figure 3.21 Average number of items purchased per person per session.

In condition 1, each user selected an average of 16.3 items in one session (SD = 6.5); in condition 2, the number was 18.8 (SD = 7.5); and, in condition 3, the number was 23.7 (SD = 7.9). To understand what effect the game element had on purchases, I performed the pairwise comparisons using the Bonferroni method between conditions 1 and 2. The results showed that there was no significant difference between conditions 1 and 2 ($p = 0.11$). However, there was a significant difference between conditions 2 and 3 ($p = 0.001$) as well as conditions 1 and 3 ($p < 0.001$).

3.6.2 Experiment 2

Purpose

In experiment 2, I explored how social cues (competitive and non-competitive interaction) affected the use of the system using a within-subjects design.

Participants

I invited another six student volunteers (three female) between the ages of 20 and 27 from the laboratory to participate in the online shopping simulation experiment (M = 23.8). They were not informed in advance of the purpose of the experiment and the systems to be used. All participants had experience using the traditional point system and had played at least one multiplayer video game.

Conditions

Mission, text and AR-based feedback were included in all systems in experiment 2. In other words, all game elements in experiment 1 were included in experiment 2.

In **condition 3**, the system was the same as the system of **condition 3** in experiment 1.

In **condition 4**, the system enabled competitive interactions. In **condition 4**, in addition to obtaining feedback from the AR-based feedback, users can compete with others through competitive interaction after shopping.

In **condition 5**, the system enabled non-competitive interaction. In addition to obtaining feedback from the AR-based feedback, users can give virtual food away through non-competitive interaction after shopping.

The order of conditions was randomized, following the counterbalanced measures design [99]. The experiment was carried out in a controlled setting environment. Since I did not give users external rewards in competitive and non-competitive interactions, we can compare groups to understand how social cues promote the use of the system.

To sum up, the only difference between **condition 3** and **condition 4** was whether there was a competitive interaction. The only difference between **condition 3** and **condition 5** was whether there was a non-competitive interaction. I expect that after adding social cues, users are willing to spend more time using the system.

Procedure and Data Collection

To conduct the study, six participants performed three conditions, each for five days. The task is the same as that in experiment 1. The shopping website and shopping process were the same as in experiment 1. The introduction process before the experiment and the help provided by the researcher were the same as those in experiment 1. Under all conditions, users were free to choose products, and there was no mandatory requirement for the completion of mission. The timer in Unity was activated to record the usage time of each function of the system in each condition.

Results

I summarize the experimental results under the three conditions and list them in Table 3.1. Under the three conditions, the mission and value point and pet interface of three systems were the same and users were free to use any interfaces. Therefore, the increase in system usage duration can prove that users were more willing to use the system.

Table 3.1 Average time per person per session under each condition.

Time (min)	Condition 3	Condition 4	Condition 5
Online shopping time	11.52	17.38	19.30
Time (s)	Condition 3	Condition 4	Condition 5
Mission interface	6.79	9.60	13.06
Value point and pet interface	12.14	15.94	20.60
Competitive interaction interface	–	23.97	–
Non-competitive interaction interface	–	–	18.31

(1) **Competitive Interaction:**

The usage time of each interface (i.e., mission, value point and pet, and competitive interaction interface) of the system was recorded (see Figure 3.22). In condition 3, each user used the system for 18.93 s on average in one session (SD = 5.2); under condition 4, the number was 49.51 s (SD = 8.8).

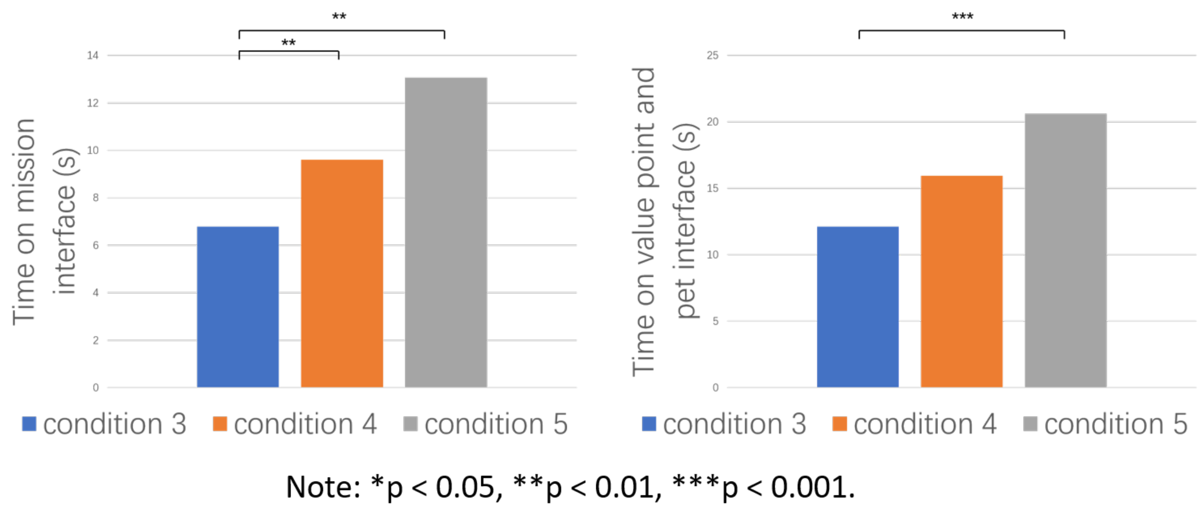

Figure 3.22 Average usage time of mission interface, and value point and pet interface per person per session.

I compared the mission interface and the value point and pet interface in conditions 3 and 4. In condition 3, the average time spent by each user on the mission interface per session was 6.79 s; under condition 4, it was 9.60 s. In condition 3, the average time spent by each user on the value point and pet interface per session was 12.14 s; under condition 4, it was 15.94 s. I performed pairwise comparisons to compare changes under the two conditions. The results showed that there were significant differences between the mission interface under conditions 3 and 4 ($p = 0.008$).

(2) Non-competitive Interaction:

Similarly, I compared the usage time of each interface (i.e., mission, value point and pet, and non-competitive interaction interface) under conditions 3 and 5 (see Figure 3.22). In condition 5, each user used the gamified point system for 51.98 s on average in one session (SD = 10.2).

I compared the mission interface and the value point and pet interface under conditions 3 and 5. In condition 5, the average time each user spent on the mission interface per session was 13.06 s and the average time spent by each user on the value point and pet interface per session was 20.60 s. Pairwise comparisons using the Bonferroni method was performed to compare the changes between conditions 3 and 5. The results showed that, under conditions 3 and 5, there was a significant difference between the mission interface ($p = 0.004$), as well as between the value point and pet interface ($p = 0.0004$). I also observed that the time spent on online shopping website increased in condition 5, compared to condition 3.

(**3**) **Competitive interaction vs. Non-competitive interaction:**

I compared conditions 4 and 5 to explore the effects of competitive and non-competitive interactions. Pairwise comparisons using the Bonferroni method were performed to compare the difference in usage time of gamified point system between conditions 4 and 5. The results showed that there was no significant difference in mission interface ($p = 0.07$), value point and pet interface ($p = 0.06$), and total usage time ($p = 0.33$).

3.7 Summary of Results

Based on the results of experiment 1, pet-based feedback was found to be effective at motivating users to participate and increasing their purchases, while the mission has a clear guiding effect on purchases. Generally, financial incentive is the factor that promotes user behavior change [100]. Our research proves that non-financial incentive can also be an important way to promote changes in user behavior [101].

According to the results of experiment 2, the usage of the same interface, and the time spent on shopping websites, improved significantly after adding social interactions. This indicates, to some extent, that the introduction of social interaction positively influences the use of the system and online shopping. By comparison of competitive and non-competitive interactions, I believe that both competitive and non-competitive interaction promotes the use of the gamified point system.

3.8 Discussion

The short-term effects and long-term effects can be somewhat different since users are getting familiar with the experiment operation or get bored after the long-term experiment. My research observed changes in users' shopping behavior in a five-day shopping in each condition. Compared to verifying it in a long-term study, I believe that how to extend the sustained impact of the gamified system is more important. I give the following suggestion to ensure the sustained impact of gamified point system, and provide some reference for the design of the gamified system:

(1) The game can be continuously updated to provide new challenges to maintain long-term participation. Zhao et al. [102] found that the decrease in long-term engagement was observed to be reversible with periodic updates to the game. (2) The gamified system is intended to encourage people from initial participation in activities to the establishment of new routines. In Lin et al.'s study [34], although most players' enthusiasm for the game decreased after the game's first two weeks, they found that individuals had, by that time, established new routines in their daily lives. Based on the above considerations, we can periodically update game features (i.e., mission, AR-based feedback, and social cues) of the gamified point system in the initial use to maintain user participation over a period of time and finally establish their daily life patterns. The system can provide periodic changes of mission with different difficulty to provide new challenges. It could be an important way to ensure that gamified point systems or gamified systems promote long-term behavioral changes.

3.9 Summary

While AR, gamification, and social factors are considered potential tools to increase user participation, how to incorporate these factors remains a difficult task. I explore a novel approach to integrate gamification and social interaction into a point system based on AR. I evaluated the gamified point system through experiments. My research draws two main conclusions: (1) Gamification helps to increase user participation in online shopping; (2) Social cues (competitive and non-competitive interactions) motivate users to use the gamified point system.

My main target using gamification is for promoting value creation (i.e., missions). In addition, I also examined gamification in promoting purchases and system usage. In Chapter 2, I examined completed missions, purchases, and system usage. I only found that system usage is increased in condition 3. In Chapter 3, the system includes game elements and a multi-user environment. I examined the game elements in experiment 1 and the multi-user environment in experiment 2. I found that the game elements promote more missions and more purchases in experiment 1, and the multi-user environment promotes higher system usage in experiment 2. Therefore, the system promotes value creation, purchase, and system usage.

Based on the above results, I believe that combining gamification and social interactions with marketing has a lot of potential, as they help to promote user engagement and influence user behavior.

Chapter 4

Virtual Marker Technique to Enhance User Interaction in a Marker-Based AR Framework

4.1 Background

The evolution of AR technology has created different types of AR for various purposes [103]. AR can be combined with other new technologies, thus it has been widely used in various fields such as education [104, 105, 106], medicine [107, 108, 109], robotics [110, 111, 112], and manufacturing [113, 114]. Previous research has investigated the state of the art technology in this area by reviewing some recent applications of AR technology as well as some known limitations regarding human factors in the use of AR systems [115, 116, 117]. Some studies have mentioned some technical challenges faced in future AR applications—for example, binocular (stereo) view, high resolution, colour depth, luminance, contrast, field of view (FOV), and focus depth [118, 119, 120, 121, 122, 123].

Aside from the technical challenges, the user interface must also follow some guidelines [124].

Interaction is an important aspect that has been widely discussed [120, 125]. Early AR interfaces used input techniques inspired from desktop interfaces or virtual reality, but over time more innovative methods have been used, such as tangible AR [126, 127] and natural gesture interaction [128, 129]. User issues encompass such things as ease of use, whether the hardware necessary for AR will reach an acceptable design that people will want to wear and use, and whether the technology will be accepted as part of daily life [130]. For example, if the cost of using an AR system is too high, this may affect the social acceptance of the system. Therefore, one of the most important aspects of AR is to create appropriate techniques for intuitive interaction between the user and the virtual content of AR applications [124].

There are three different types of AR, which are marker-based AR, markerless AR, and location-based AR [131, 132, 133]. Marker-based AR is used when what the user is looking at is known [134]. It has been proven to be sufficiently robust and accurate, and so far almost all AR software development kits support marker-based tracking methods [135]. Marker-based AR gives the position of the marker in the camera coordinate system [136]. Therefore, the sequence of markers can be determined by obtaining the coordinate information of multiple markers. Coordinate information can be used to combine multiple markers to complete some control functions [137]. In fact, although many AR sdks support the simultaneous recognition of multiple markers, there have been few in-depth studies on the cooperation of multiple markers [138].

There are some problems in marker-based AR systems. In marker-based AR systems, markers are usually relatively independent. Moreover, the markers are predefined by the system creator in advance, and users can only use these predefined markers to complete the construction of certain specified content [139]. Therefore, such systems usually lack flexibility and do not allow users to create content freely.

In this research, I propose a virtual marker technique to build a marker-based AR system framework where multiple AR markers, including virtual and physical markers, work together. Virtual markers are generated from physical template markers or existing virtual markers. Virtual markers mainly consist of function markers, variable markers, and number markers. Users can completely customize these markers and use them. Therefore, such a framework has the scalability to complete more complex functions. In addition, the virtual marker technique can be used to manipulate AR objects more conveniently, which enhances the interactivity and scalability of the marker-based AR system. I divide the cooperation of multiple markers into two categories—one is an ordered series of markers, such as that used in tangible programming, and the other is an unordered series of markers. I have designed a set of gestures for virtual marker operations so that they can be used in the same way as physical markers. Multiple markers can be used as control commands as well as inputs and outputs. I have implemented a prototype system to illustrate my framework. The system includes multiple markers, a webcam, a leap motion, and software. The user can arrange multiple markers in a specific order to create a program or connect markers through hand gestures, then the result will be presented in the form of AR. I conducted a pilot study on the marker-based system that introduced the virtual marker technique to understand its potential value in an AR system.

4.2 Related Work

Markers are widely used in various AR systems as information carriers or positioning tools. In this section, I describe in detail the related work and their limitations, as well as the advantages of my proposed methods and work. In order to solve the customization problem in the multi-marker system, I propose a brand-new virtual marker technique. The relationship between related work and my proposal is shown in Figure 4.1.

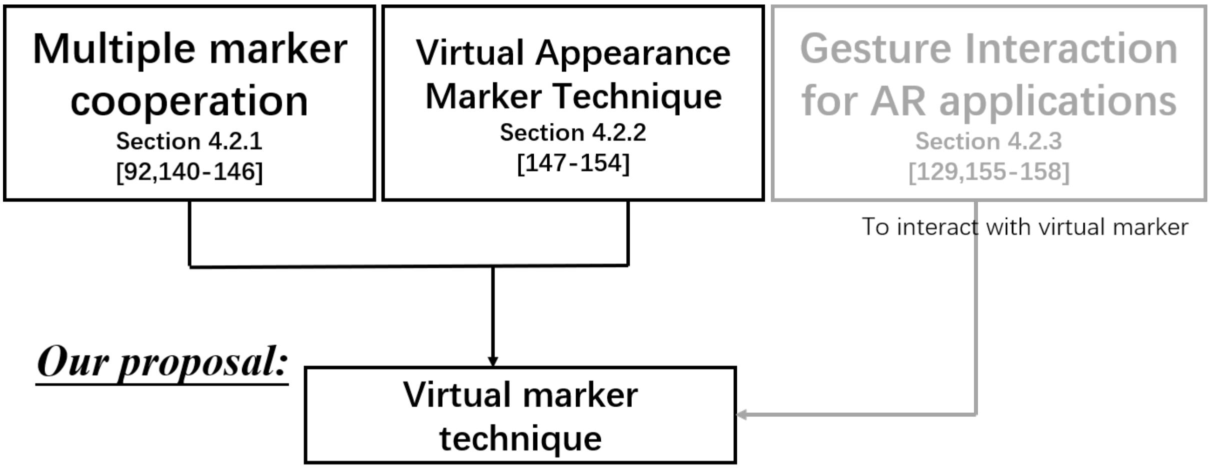

Figure 4.1 The relationship between the related work and my proposal.

4.2.1 Multiple Marker Cooperation

In AR systems, the use of markers is very common. Markers are normal images or small objects which are trained beforehand so that they can be recognized later in the camera stream. After a marker is recognized, its position, scale, and rotation are derived from visual cues and transferred to the virtual information.

However, few studies have explored how to establish the connection between multiple markers. Due to its physical characteristics, multiple markers are often used to provide more accurate detection and tracking in AR systems [140, 141].

Zeng et al. [142] developed an AR application, in which the virtual keys can be accurately superimposed on piano keys using multi-marker tracking.

Multiple markers are only used to provide tracking and positioning, which obviously ignores the ability of AR markers to carry AR information. Therefore, some studies used multiple markers to provide tangible programming [92, 143, 144].

Their research proposed programming tools or games using tangible blocks and AR for children. Children could create their programs by arranging programming blocks and see AR contents.

But the markers were preset in advance and users can only complete some specific content construction. Therefore, this kind of research on tangible programming using multiple markers has a common problem, that is, the programming ability is simple.

In order to solve this problem of tangible programming, some studies have expanded the interactive capabilities of markers to provide users with creative activities [145, 146].

In the work of Tada et al. [145], the authors implemented a prototype system that was capable of drawing and moving shapes with multiple physical markers. It was possible to edit the program by writing on paper cards. The creative activities are still limited although it has been improved. For example, the user can only change the variable from 1-10 by writing on the marker.

4.2.2 Virtual Appearance Marker Technique

The marker is the carrier of content in a marker-based system. The freedom to provide user-defined content means that a lot of markers are required. Unless we know what markers users will use, it is very difficult to prepare a large number of markers because markers need to be registered in the system in advance before they can be recognized by the system. Therefore, I consider markers with virtual characteristics to solve this problem.

Many studies provide signs with virtual appearance to resolve the obtrusiveness of visual marker [147, 148, 151]. Park et al. [149] present an AR system using invisible markers which are created with an infrared (IR) fluorescent pen. The main idea is to use an additional external camera with IR functionality to track IR markers that are not detectable in the camera.

It can be applied to indoor positioning [150] to improve the indoor AR tracking. Since there is no need to place markers in the physical space, the high environmental adaptability feature allows the system to position virtual objects at the desired location.

In the above research, the markers are all invisible to the user. But these markers actually exist and provide users with positioning ability. The appearance of the marker is changed to reduce the impact on the user's visual environment.

Some studies have focused on changing the display of markers to provide interactivity different from static markers. Häkkilä et al. [152] proposed a technique to use visible, fiducial markers, by projecting them ad hoc from a handheld projector. This interaction technique, where one person (the guide) is projecting a marker and other users can read it with their mobile devices, enables in situ information delivery. This technique converts the marker from a static paper marker to a projected marker, thus changing the display form of the marker and the way the user interacts with the marker.

There are also studies trying to make the marker more tangible [153]. Aero-Marker was proposed that has both a virtual appearance and physical features. It integrates a blimp with an AR marker. While a conventional AR marker is generally paper-based and static, Aero-Marker floats in the air and moves toward the user, thereby changing the relationship between the user and the marker. Virtual information is overlaid on the entire surface of the blimp, which makes the virtual information tangible.

The above studies have changed the display of the physical markers to virtual or tangible objects, but they do not have the ability to change the content of the markers.

Peiris et al. [154] proposed markers that can be changed due to external stimuli. They print patterns on an AR marker using thermochromic inks of various actuation temperatures. Thus, as the temperature gradually changes, the marker morphs into a new marker for each temperature range.

Although this technique can be used to make a piece of paper marker into different markers according to different environments, these marker information still needs to be registered in advance. We need a marker that can display different content and allow users to freely create content. In addition, this marker does not need to be registered in advance.

Therefore, I proposed a virtual marker technique based on the above studies. The virtual marker has a similar appearance to the physical marker. This technique allows users to customize and generate virtual markers through existing markers. The virtual markers can be dynamically generated when the system is running and do not need to be registered in advance. Virtual markers can work the same as physical markers. Therefore, this technique solves the existing customization problem and can be widely used in AR systems.

4.2.3 Gesture Interaction for AR applications

Since I have proposed virtual marker technique, there is a need to consider how to interact with virtual markers. I choose to use gestures as an intuitive way to interact with virtual markers.

Gesture recognition is a topic in computer science and language technology with the goal of interpreting human gestures via mathematical algorithms [155]. Users can use simple gestures to control or interact with devices without physically touching them. Gesture recognition can be seen as a way for computers to begin to understand human body language, thus building a richer bridge between machines and humans than primitive text user interfaces or even GUIs (graphical user interfaces), which still limit the majority of input to the keyboard and mouse and interact naturally without any mechanical devices [156]. In virtual and augmented reality, gestures are also a natural way to interact with virtual content.

Lee et al. [157] developed a 3D vision-based natural hand interaction method. One of the steps is simple collision detection based on short-finger rays, which is used for interaction between the user's finger and the AR object.

However, the user gesture operations in this study only supported simple pointing and touching. In order to support the capture of gestures, some studies used some additional equipment such as markers or gloves to help capture gesture information.

Bellarbi et al. [158] presented a hand gesture recognition method based on color marker detection. The user can perform different gestures, such as zooming, moving, drawing, and writing, on a virtual keyboard.

But wearing additional equipment may affect the user's operation and burden the user. Moreover, it used only the index finger and thumb to perform simple interactions without complete palm information. Some studies used the improved recognition algorithms to recognize free-hand gestures without the use of additional equipment or markers.

Yang et al. [129] incorporated AR and CV algorithms into a Virtual English Classroom to promote immersive and interactive language learning. By wearing a pair of mobile computing glasses, users can interact with virtual content in a three-dimensional space using intuitive free-hand gestures.

In this study, users did not need to wear additional equipment or color markers on their fingers. Only the fingertip information was used in the system and the complete palm information was not used.

My previous research used leap motion as the depth sensor to track the full hand [159]. Users did not need to wear additional equipment. The support vector machine was employed to recognize the hand shapes and motion. By combining the hand shapes and motion, we achieved recognition of hand gestures including palm and fingertips.

In this research, I used this method to recognize different gestures that interact with virtual objects in the system. In the system, we can use a variety of gestures to operate on virtual objects but also dynamically modify the value of virtual objects. In addition, gestures can also be used as system instructions and in some cases coordinate the work of physical and virtual markers.

4.3 Virtual Marker Technique

In this chapter, I will introduce the virtual marker and its generation and operation.

4.3.1 Why virtual markers

In marker-based AR systems, markers are usually relatively independent. Moreover, markers are predefined by the system creator in advance, and users can only use these predefined markers to complete the construction of certain specified content. Therefore, such systems usually lack flexibility and do not allow users to create freely. However, unless the operation performed by the user is predictable, it is often difficult to accurately provide a large number of physical markers. Therefore, I propose a virtual marker technique to solve these problems. Virtual markers provide two main advantages. The first advantage is that they allow users to use simple template markers to customize the content, including function names, variable names, and numbers. This can solve the inconvenience of providing users with a large number of physical markers. The second advantage is that virtual markers can be used to store combined information. That is, the content of the virtual marker can be changed in real-time. Users can continuously process and merge content to achieve more complex functions.

4.3.2 Virtual marker

A virtual marker is a marker that does not exist in the real world but that can be seen in an AR scene. It can work the same as a physical marker. In an AR scene, physical markers, and virtual markers can work together. When the system is running, the information from the physical markers and the virtual markers will be read to compose complex information or instructions.

Virtual markers have a similar appearance to physical markers but have user-defined information marked in red (see Figure 4.2). They can be used with physical markers naturally. The virtual marker connects the real world and virtual world in the system. It is a virtual object generated by physical markers but it can work with the physical marker, which means that it can interact with the real world. It can also interact with the virtual world—for example, as a finger ray from a virtual hand. Therefore, a virtual marker represents the alignment of the virtual world and the real world.

Figure 4.2 Physical and virtual markers. In the AR scene, there is a physical number 3 marker (**left**) and a virtual number 3 marker (**right**). The border of the virtual marker is adjusted to gray.

4.3.3 Basic virtual marker generation

Virtual markers mainly consist of function markers, variable markers, and number markers. I provide two input markers, a number input marker and a keyboard input marker (see Figure 4.3).

Figure 4.3 Two input markers. They can accept the corresponding input parameters through the user clicking on the marker. The content of each block represents the input information when the user clicks on the block. The CE button is used to delete the last number or character, and the OK button is used as a confirmation button.

The number virtual marker is generated by a physical constant marker and a number input marker (see Figure 4.4).

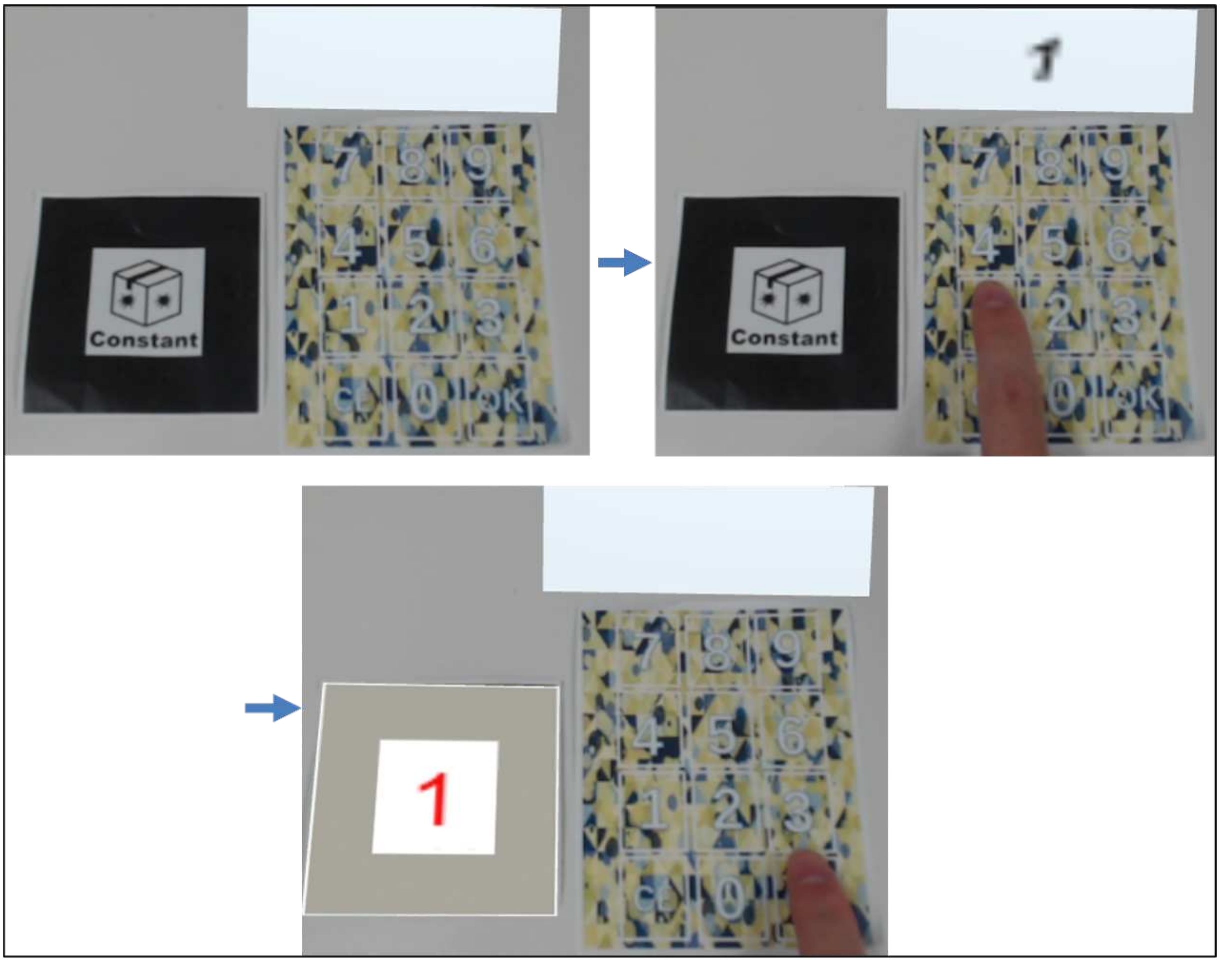

Figure 4.4 The process of creating a number virtual marker. The user first places a number template marker and a number input marker under the camera. After the system recognizes two markers, an AR display screen will be generated above the number input marker. When the user clicks on the number input marker, the input information will be displayed on the AR display screen. After the user confirms the number, a number virtual marker 1 is generated.

The function virtual marker is generated by a physical function marker and a keyboard input marker. The variable marker is generated by a physical variable marker and a keyboard input marker. The system will provide a corresponding template to generate virtual markers based on the recognized markers. The information entered by the user will be recorded by the system and combined with a virtual marker template to generate a specific virtual marker. Virtual markers will be generated at the locations of physical markers (constant, function, and variable markers). After being generated, the user can freely move the virtual marker and continue to generate new virtual markers.

4.3.4 Combined marker generation

The virtual markers can be combined to generate a new virtual marker that carries combined information. The user arranges the physical marker and the virtual markers in order and uses gestures to complete the creation of the combined virtual marker. The system will determine the content of the combined virtual marker according to the marker sequence and the number as well as the category of the virtual markers.

The user can place a physical marker named set, a variable virtual marker, and a number virtual marker in sequence. After the user performs the defining gesture, the system will generate a new virtual marker containing the corresponding variables and number information at the position of the physical marker (see Figure 4.5). The user can also place a physical marker named 3D and three number virtual markers in sequence to generate a 3D vector marker. After the combined virtual marker is generated, the system will not automatically clear the original virtual markers, meaning that users can continue to use these markers to create new combined virtual markers. These combined virtual markers can be easily used to control AR objects in the system.

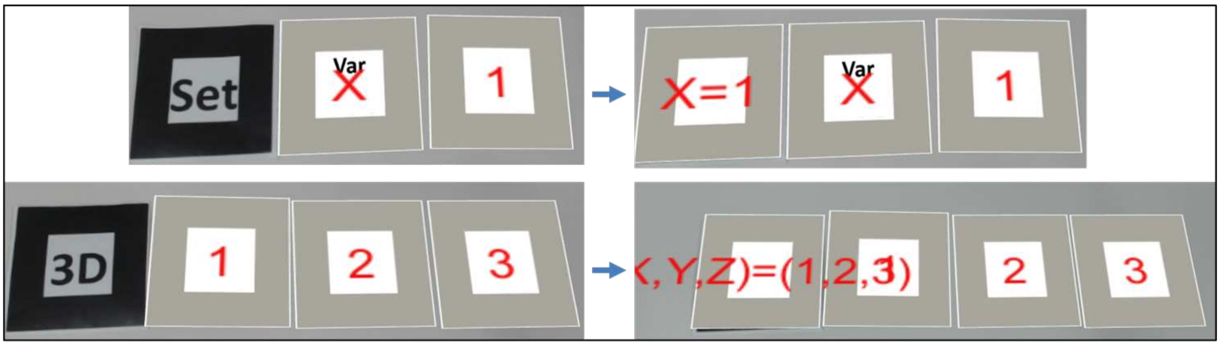

Figure 4.5 Examples of generating a virtual marker containing combined information from basic virtual markers. The first virtual marker (X = 1) is generated by a variable virtual marker (X) and a virtual number marker (1). The second is generated by three virtual number markers. The user can determine the information of the 3D vector marker by changing the marker selection order.

4.3.5 Manipulating Virtual Marker

Virtual markers are essentially virtual objects. The user can interact with physical markers by grabbing and moving. Similarly, users can use hand gestures to manipulate and interact with markers in the system. In the current design, I use right-hand gestures.

There are some descriptions of these hand gestures (see Figure 4.6):

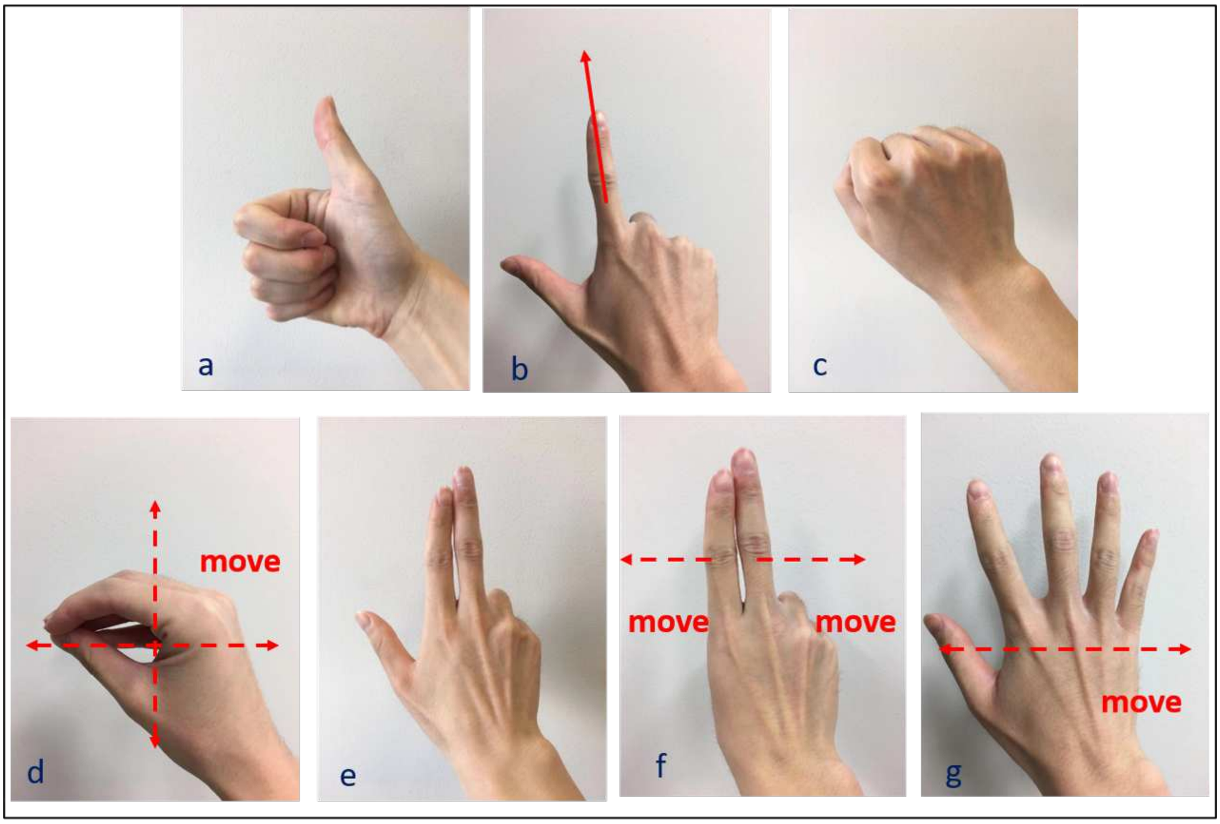

Figure 4.6 Hand gestures that are used to control virtual markers. (**a**) is a defining gesture. (**b**) is a selecting gesture. (**c**) is deselecting gesture. (**d**) is a dragging gesture. (**e**) is a copy gesture. (**f**) is a parameter/value change gesture. (**g**) is a deleting gesture.

(a) Defining gesture: This gesture is a thumb-up gesture that will tell the system to define the current command and execute it.

(b) Selecting gesture: The user needs to spread his thumb finger and index finger. The index finger will emit finger rays for selection in the AR scene. The user can use the finger ray to select virtual markers for manipulation. In order to express the selected state of the virtual marker, the system will highlight the selected virtual markers in red.

(c) Deselecting gesture: When the user makes a clenched fist, the state of the selected marker at this time will be restored to the unselected state.

(d) Dragging gesture: The dragging gesture needs to gather all fingers in one point. Using this gesture, the user can drag and change the position of the virtual markers in the selected state. The user can use this gesture to arrange virtual markers.

(e) Copy gesture: The user stretches their index finger, middle finger, and thumb while tightening the other two fingers. The user can use this gesture to copy the selected virtual markers. After the copy is complete, the virtual markers will be restored to the unselected state.

(f) Parameter/value change gesture: If the index finger and middle finger are extended and the other fingers are retracted, accompanied by a certain rightward movement speed, this is regarded as an increase in the number or parameter. Each time the user swipes to the right, the parameter value will increase by one. If the index finger and middle finger are extended and the other fingers are retracted while moving to the left at a certain speed, this is considered as a decrease in the number or parameter. Each time the user swipes to the left, the parameter value will decrease by one.

(g) Deleting gesture: To make this gesture, the user needs to open all their fingers and hand palm and move their hand left and right with some speed. With this gesture, the user can delete the selected virtual markers in the scenery.

It is worth noting that different users may be accustomed to different gestures. In fact, I am more concerned with what kind of interaction users can perform using hand gestures.

4.4 How to Apply Virtual Marker Technique in Different Levels in Marker-Based AR System

This section introduces the virtual marker technique in a marker-based AR system. I divide the use of virtual markers into different levels. Level 1 uses virtual markers to do virtual marker programming. Users can define complex content such as functions by customizing virtual markers. In level 2, users can use virtual markers to control AR objects. In level 3, users can combine levels 1 and 2 to program the behavior of AR objects through virtual marker programming. Through the use of different levels of virtual markers, we can perform precise and complex control in marker-based AR systems.

4.4.1 Level 1: Virtual marker programming

In the system, virtual markers can be used in conjunction with marker-based tangible programming to provide scalability and customization. I named this virtual marker programming. Markers and hand gestures will be used in virtual marker programming. Each marker contains information, and multiple markers will be placed in the scene in a specific order. The arrangement will be read and recognized by the system and a visualization program will be generated. Since it is difficult to accurately identify a large number of markers at the same time, I propose an information combination method. Information from multiple markers will be merged and become the content of the first marker. After that, the user can use a single marker to replace the previous multiple markers to make more complex programming. In the AR scene, virtual and physical markers can be observed at the same time. These markers will be located in the same coordinate system. Therefore, the system can obtain a marker sequence composed of virtual and physical markers. Language syntax structures are provided for virtual marker programmings, such as condition structure and loop structure. The architecture of the system can be expanded on this basis and more structures can be introduced.

I use an example to illustrate how gestures and virtual markers are used (see Figure 4.7). By using a defining gesture, the user can merge the content of multiple markers into the first marker. The user can copy the marker using selecting and copy gestures. When the marker is selected and the user performs a value change gesture, the value of the selected marker will be modified. In this example, I show how the information of the virtual markers can be combined.

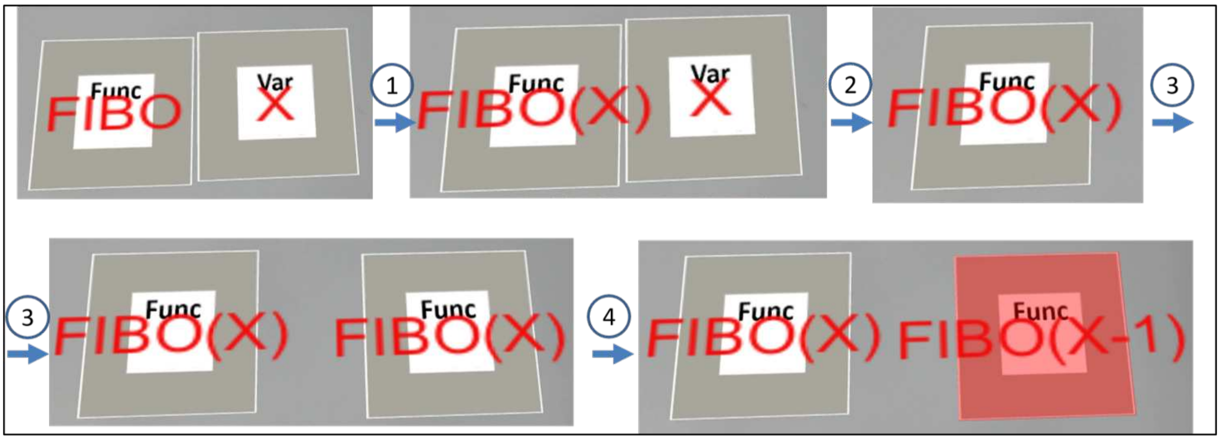

Figure 4.7 An example to illustrate how to combine the content of multiple markers, operate markers, and modify the marker parameter. First, the user creates function and variable virtual markers. In step 1, the user uses a defining gesture to combine the contents of the two virtual markers into the first virtual marker. In step 2, the user selects a variable virtual marker and uses a deleting gesture to delete the variable virtual marker. In step 3, the user selects the virtual marker and uses the copy gesture to copy it. After completing the copy, the user places the two virtual markers in different positions through dragging gesture. In step 4, the user selects the virtual markers by selecting gesture and uses the parameter/value change gesture to modify the parameter of the selected marker.

Based on this example, users can complete more complex virtual marker programming (see Figure 4.8). The user can merge the combined information into the first marker using a defining gesture. The final function definition can be formed through multiple markers that already contain combined information.

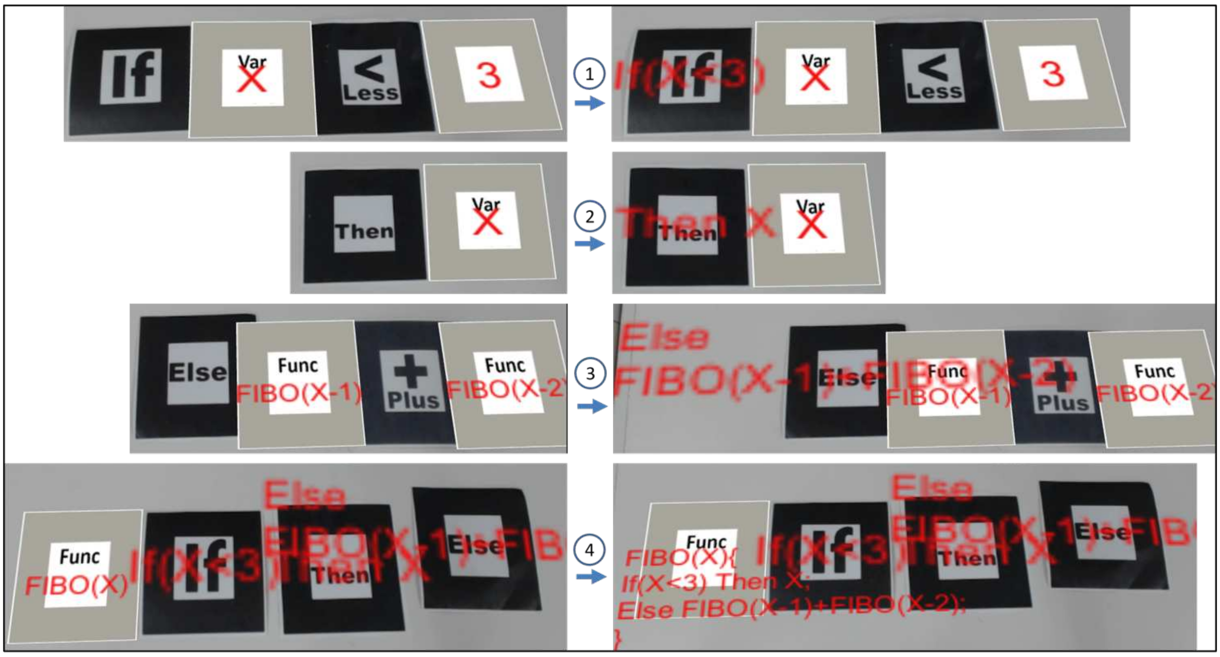

Figure 4.8 An example of Fibonacci function definition using virtual and physical markers. In steps 1, 2, and 3, the user arranges the virtual and physical markers in order and merges the combined information into the first physical marker (If, Then, and Else markers) through a defining gesture. When the combined information is added to the physical markers, the combined information will be superimposed and displayed on the physical markers in the form of AR. In step 4, the user arranges the function virtual marker and the defined If, Then, and Else physical markers in order and merges the combined information into the function virtual marker through a defining gesture to complete the function definition. The function marker has already been defined and can be used for further combination.

4.4.2 Level 2: AR objects control

In the framework, I show several examples to illustrate how users can control AR objects through virtual markers containing combined information (including movement, rotation, and action).

Movement and rotation control

In the system, I illustrate an example of applying multiple markers to control the movement and rotation of a car.

A virtual car will be displayed on top of the car marker. The car marker can receive multiple types of control markers as parameters, such as moving markers and rotation markers (see Figure 4.9).

After the user connects the car marker with the moving marker or the rotation marker with a selecting gesture, the user can move and rotate the car by touching the text block on the moving or rotation marker. This is an example of using multiple physical markers for control in a typical marker-based AR system.

The control of AR objects based on markers usually cannot accept parameters from users. With the help of virtual markers, users can use custom data information as input in the system to accurately control the movement and rotation of the car. The user can select multiple markers to be connected through hand gestures. When markers are selected, the markers will be highlighted in red. A moving or rotation marker can accept the combined virtual marker as an input parameter. The virtual marker (X=1) is generated by a variable virtual marker (X) and a virtual number marker (1). It can be used to control the movement or rotation of the car in the X-axis. The 3D vector virtual marker can be used to adjust the direction or angle of the car in 3D space.

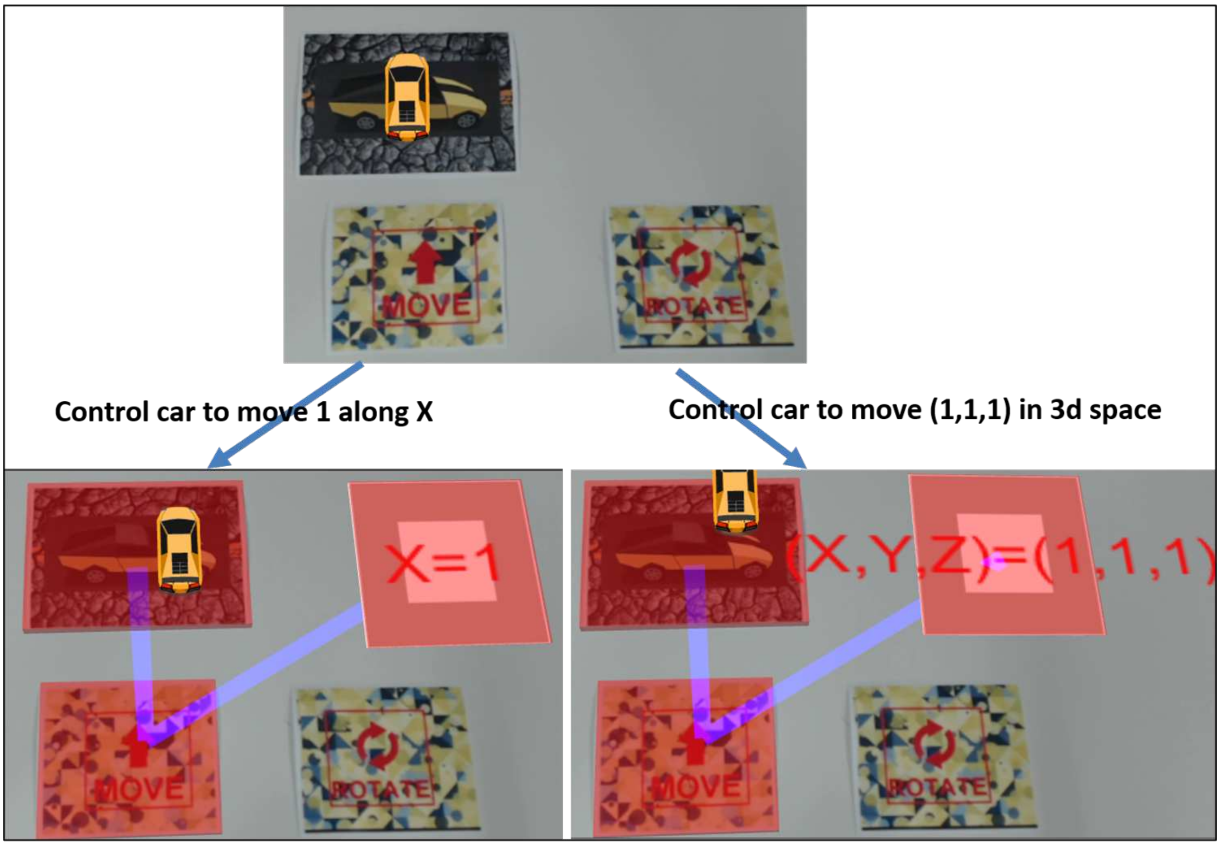

Figure 4.9 Using virtual markers to control the 2D and 3D movement of a car. In the figure above, the user can connect the car marker and any control marker to control the movement or rotation of the car. In the two pictures below, users are provided with combined virtual markers as parameters for the movement and rotation of the car. When a virtual marker is also selected and the user clicks on the moving marker, the car will move according to the parameter. In the example in the left figure, the car will move 1 along the X-axis and move in space along a 3D vector (1, 1, 1) in the right figure. Similarly, the user can also control the rotation of the car in this way.

Avatar action and scale control

In the AR system, the avatar is usually a 3D model. The size of the model is preset when the system is built. Users usually control continuous changes in the size of the model through a button, but they cannot precisely control such changes. The 3D vector virtual marker can provide this accurate size change so that the user can change the size of the model precisely. Users can generate 3D vector markers with different values through customization, then freely control the size of the avatar (see Figure 4.10).

In addition, a control method for the avatar is provided in the system. The control marker can be accepted as a parameter of the avatar marker. The user can click the text block on the control marker to control various actions of the avatar.

Virtual timer control

Another example is the use of virtual markers to set a virtual timer. A virtual timer marker is provided and a virtual timer is displayed on the marker. In the initial state, the virtual timer does not contain time information. Users can use virtual markers to customize the start time of the virtual timer. After the user selects the two-digit number marker and the virtual timer marker, the two-digit number marker can be used as a parameter of the virtual timer marker to set the left parameter of the AR virtual timer. The right parameter is also set in the same way (see Figure 4.11). The virtual timer will start to count automatically after setting. In the system, I also provide a control marker for the virtual timer. The user can control the pause, continue, and reset of the virtual timer through the control marker.

Figure 4.10 Using markers to control the size and movement of the avatar. The first image shows the avatar marker and the second image shows the avatar being superimposed on the avatar marker. The third picture shows the state of the markers before they are connected. After connecting the 3D vector marker and the avatar marker, the size of the avatar will be set to (1, 1, 1), as shown in the fourth picture. In the fifth picture, the user commands the avatar to run by clicking the control marker.

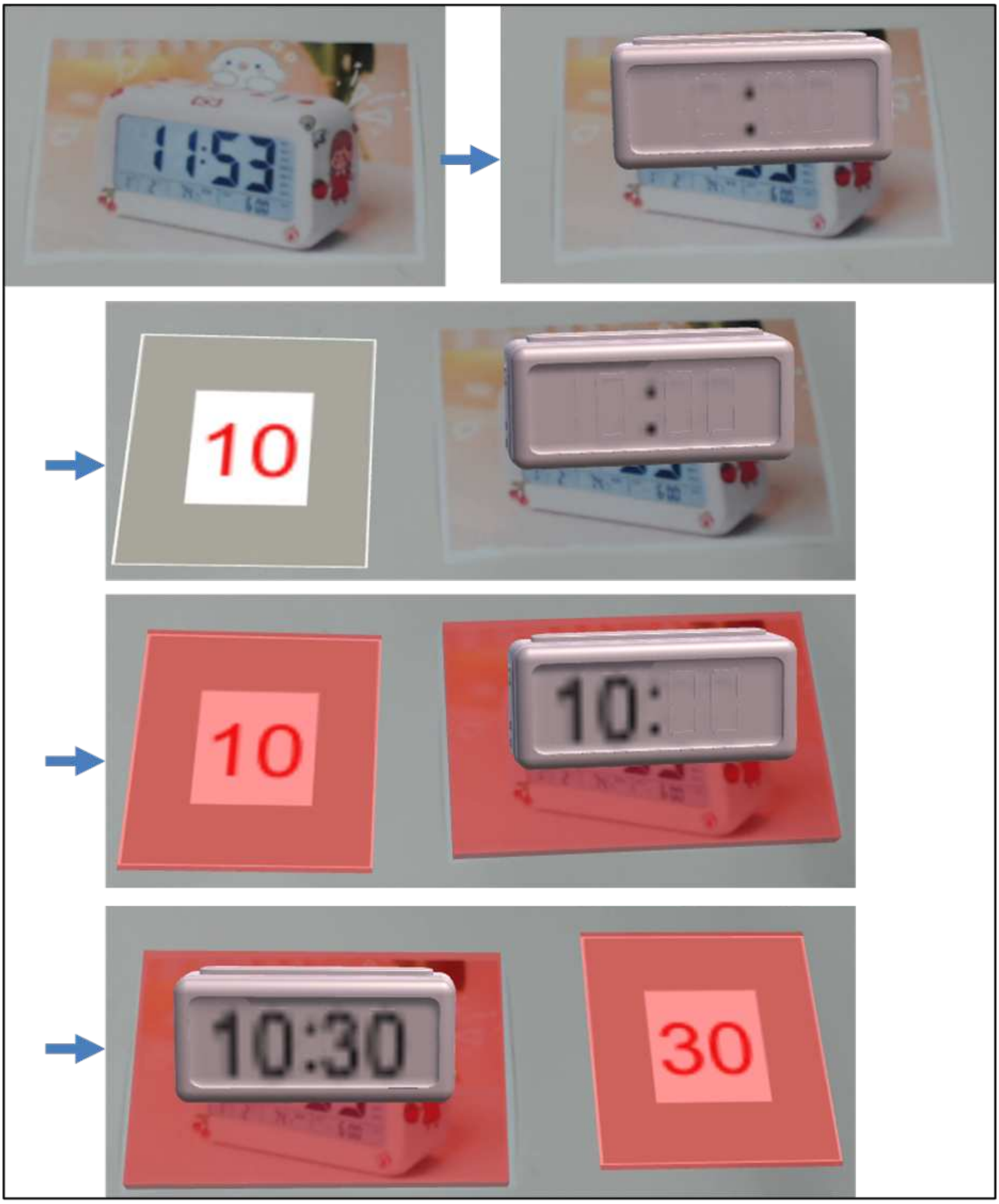

Figure 4.11 Using markers to control the virtual timer. The first picture shows the virtual timer marker. The second picture shows the initial state of the virtual timer superimposed on the marker. In the third and fourth pictures, the user connects the two-digit number virtual marker and the virtual timer marker to set the left parameter of the virtual timer. Similarly, the user can set right parameter of the virtual timer, as shown in the fifth figure. After the setting is completed, the virtual timer will automatically start timing.

4.4.3 Level 3: Combination of level 1 and 2

In addition to providing users with a basic function definition, virtual marker programming can also be used in the programming control of AR objects. The system implements two examples to illustrate how to combine virtual marker programming and AR object control together.

The first example is to control the movement of the car by programming, including 2D plane movement and 3D space movement. As shown in the figure, the user can arrange multiple markers in a certain order. The system will read the order according to the depth-first mode. In Figure 4.12, the sequence is the function marker, the left loop marker, the number 3 marker, the 3D vector marker, and the right loop marker. The defined function is that the object moves with the 3D vector of (1, 1, 1) as a parameter and repeats this movement process 3 times. Then, the user places the car marker, the moving marker, and the defined function virtual marker in order. When the marker sequence is correctly read, the user can use a defining gesture to tell the system to execute the program. After that, the car will move according to the defined function. This program has other variants. For example, users can use a rotation marker instead of a moving marker to define the rotation. Users can also use other virtual number markers to change the loop times. Markers containing variable and number information can also be used to replace 3D vector markers for movement in a 2D plane. In addition, users can freely add more combined markers to expand the program.

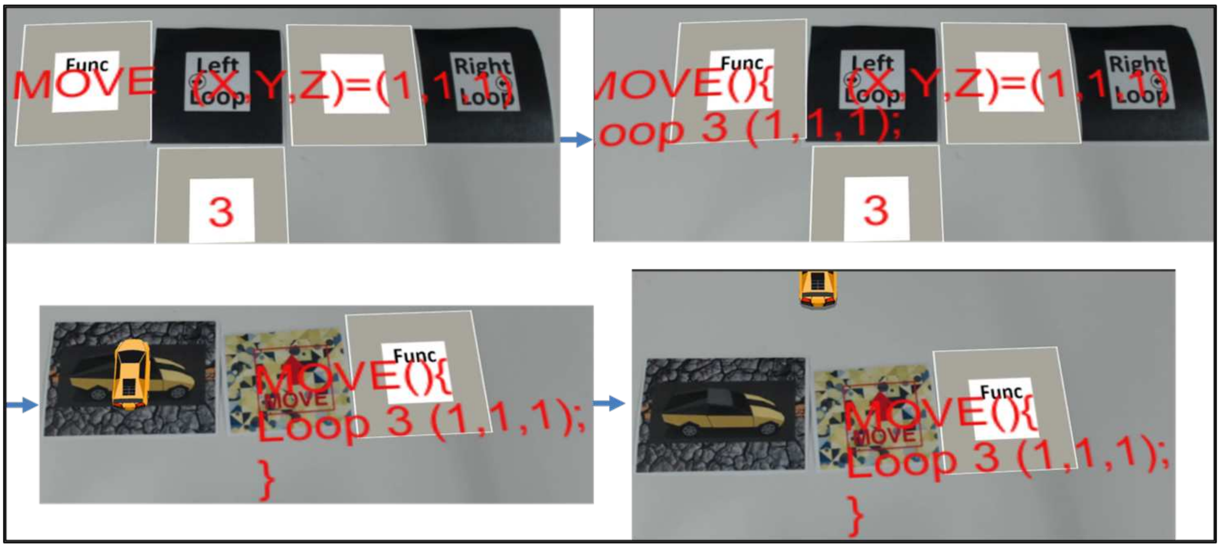

Figure 4.12 An example of controlling the 3D movement of the car. The markers will be read in a deep-first traversal mode—that is, read from left to right—and the column marker is read first when there is a column. The defined program is that the car moves with the 3D vector of (1, 1, 1) as a parameter and repeats this movement process 3 times.

The second example is controlling the avatar's action sequence and the time of each action through programming. Similarly, the user can arrange multiple markers in a certain order and the system will read the program accordingly. The sequence is the function marker, run marker, number 1 marker, idle marker, and number 4 marker. The defined process is that the object will run for 1 second and then perform casual action for 4 seconds. Then, the user places the avatar marker and the function marker in order. The user can use a defining gesture to execute the program. After that, the avatar will perform actions one by one, and each action will be executed at a user-defined time (see Figure 4.13). Users can also freely add action markers or loops to define more complex AR controls. For example, the user can add the loop marker and the number of loops as in the first example to control the repetition of the avatar's action sequence. The user can also add multiple action markers and change the time for each action to change the avatar's action.

The above two examples show how to combine virtual and physical markers to program the control of AR objects in the system. In fact, the combination of level 1 and level 2 can accomplish more control functions than the above two examples. For example, users can also define control structures under different conditions or use other structures to program the AR objects. Since the main variable information in programming is dynamically created by the user and other structural information is provided by the physical markers, such a system is extensible.

Figure 4.13 An example of controlling avatar actions. The markers are also read in depth-first traversal mode. The defined process is that the avatar will run for 1 second and then perform casual action for 4 seconds.

4.5 System Implementation

4.5.1 System Hardware

I used Logicool HD Pro Webcam c920 as the Web Camera to help detect and recognize markers in the system. And I used Velbon EX-Mini S as the tripod to fix the web camera for a stable camera view. I used a laptop as the development platform. In the system, I used a Lenovo Thinkpad X260 as the laptop. I used Leap Motion as the depth sensor to detect the hand data. Leap Motion can track the user's hands and fingers position and transfer these data to the system which will help us to recognize the user's hand gestures.

4.5.2 Development Environment

The development operation system is Windows 10 Home 64-bit, with 8 GB RAM on the ThinkPad manufactured for Lenovo. The main software I used is Unity 3D Engine 2018.4.19f1 (64-bit), which provides support for AR system development. I mainly used C# programming language as a scripting language to implement the system. In order to identify the marker, I used the Vuforia engine. To use leap motion in the system, I need Leap Motion Orion 4.0.0 and the Leap Motion Core Asset Package as software support. For gesture recognition, I used SVM for classification. In the system, I use Accord.NET API to help us recognize user gestures.

4.5.3 Multiple marker process

There are two types of processing in the system: one is a sequence of markers that rely on order, and the other is disordered multiple markers.

The marker sequence represents the logic of the visualization program. Therefore, we need to identify markers with a defined sequence. In the first step, we need to identify all the markers in the scene and access their coordinate positions in the Unity scene. Next, we will use their coordinates to obtain the sequence I defined. In this step, since we cannot accurately place the two markers on the same x-coordinate or y-coordinate, I need to set a threshold for the coordinate position to determine whether the two markers are in the same row or in the same column. After that, we will obtain a marker sequence for processing.

For disordered multiple markers, the system will first identify multiple markers. The system will establish a connection based on the markers selected by the user as input information. After establishing the connection between markers, the user can complete AR object operations by operating the markers.

Multiple sequence recognition

In the system, I have expanded the recognition function of multiple markers compared to previous research. Generally, the identification of multiple markers is to sort multiple markers in one direction.

In the research, I have achieved two improvements. The first improvement is that the system allows multiple markers to be placed and identified in two directions. The user can arrange multiple marks as shown in Figure 4.14. In the sequence 1, the markers will be recognized in the order of markers 1-2-3-4-5. The system will perform calculations based on the X and Y values of the coordinates to obtain the start marker in the field of view. In Figure 4.14, the start marker is marker 1. Then the system will look for markers in the same row, that is, markers 2 and 5 to form a sequence. Then the system will look for marker 3 in the next row and insert it after marker 2. Finally, the system will find marker 4 and insert it after marker 3 in the sequence.

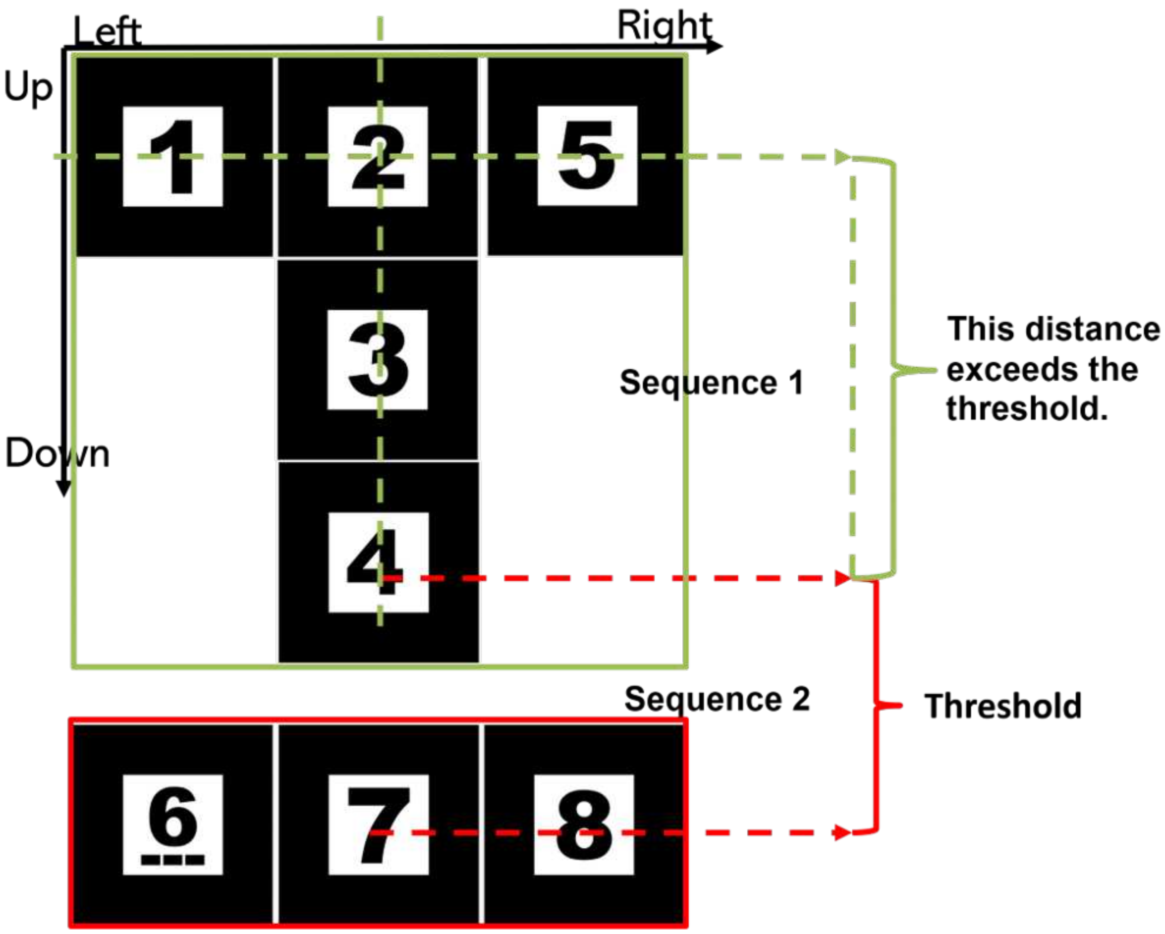

Figure 4.14 Multiple sequence recognition problem.

The second improvement is the ability to recognize multiple marker sequences. To this end, I designed and implemented a multi-sequence recognition algorithm. The system will identify all the markers in the field of view, and find the start marker based on the X and Y values of all coordinates, which is marker 1. I set a threshold for identifying different marker sequences. The system will perform the first recursive search for the qualified markers based on the distance threshold and the coordinate information of marker 1. At this point, the system will find the marker sequence 1-2-3-5. After that, the system will update the start marker to marker 3 and perform the next recursive search for a new marker until it cannot find a new marker anymore. Therefore, marker 4 is found and added to the marker sequence. This marker sequence will be saved as sequence 1. After that, the system will search for the start marker in the remaining markers and repeat the above operation until all markers are recorded in a certain marker sequence.

4.5.4 Input marker implementation

Figure 4.15 shows the feature point information of the keyboard input marker. In the system, I use a processing method based on image recognition to read the user's input. When the user occludes some feature points of the input marker by hand, the system can know the user's input according to the occluded feature points. Figure 4.16 shows the feature point information of the number input marker.

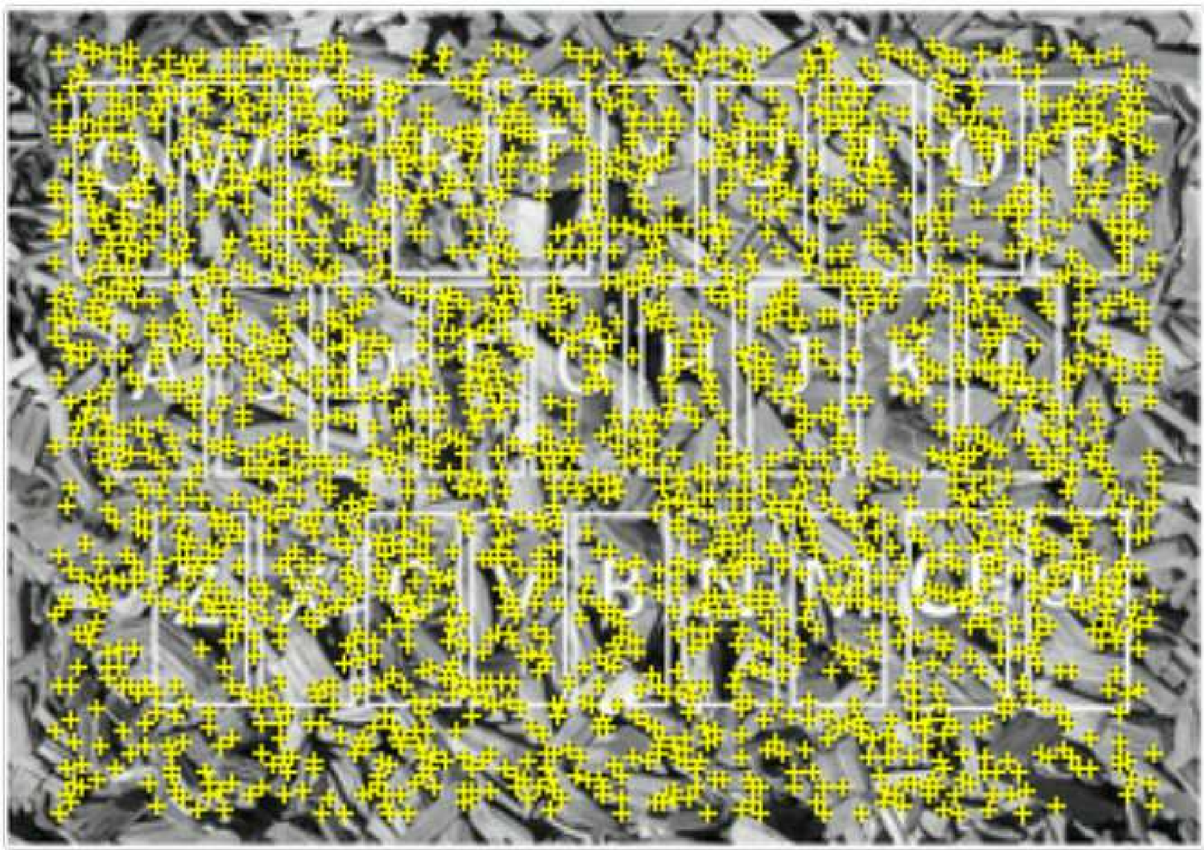

Figure 4.15 Feature points in the keyboard input marker.

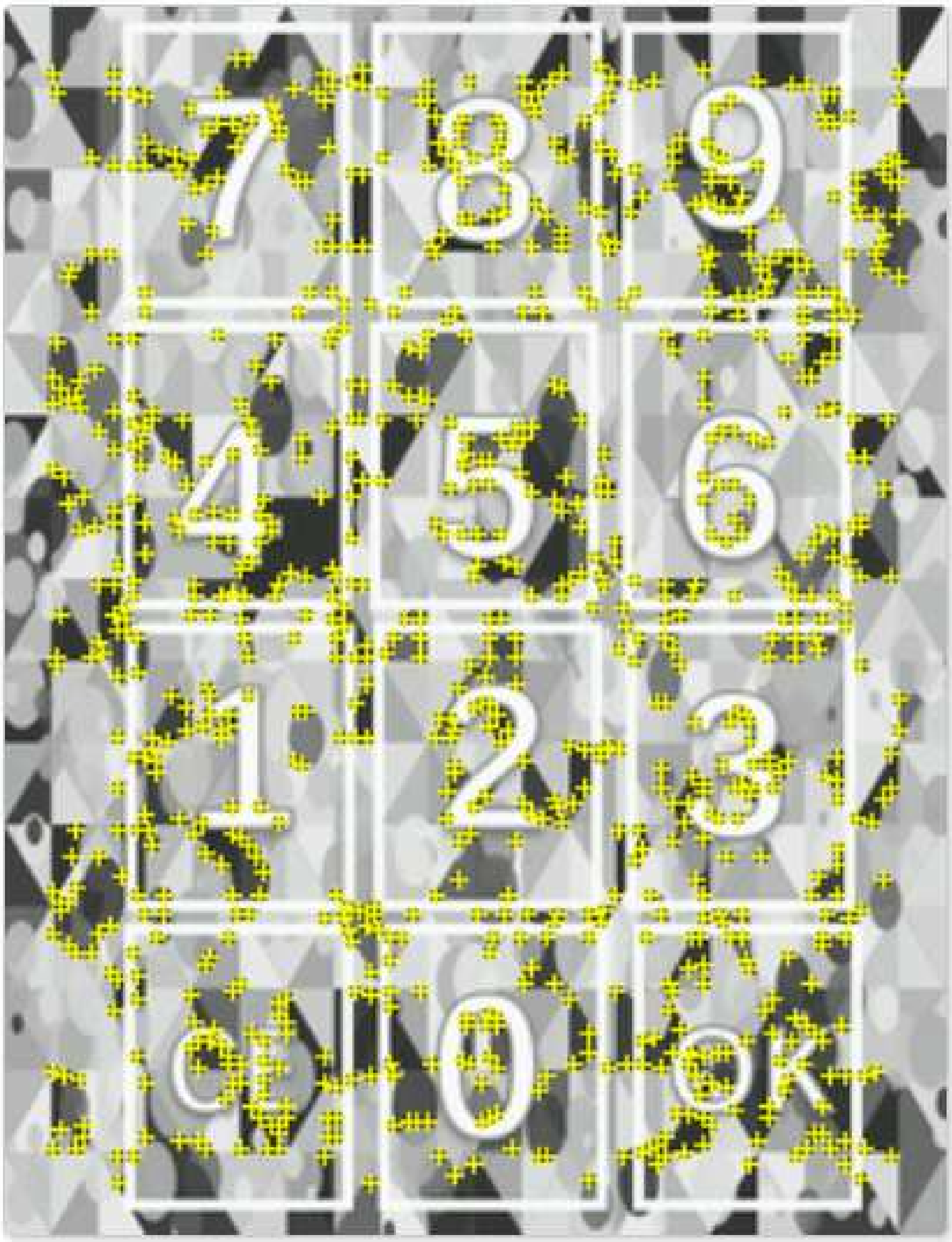

Figure 4.16 Feature points in the number input marker.

The feature point only shows the feature information on the marker. I need to set the input markers in unity to monitor user operations (see Figure 4.17 and Figure 4.18). I used the virtual button function provided by Vuforia and overlayed each input block. After that, I modify the name of the virtual button on each input block and write a script to listen to each virtual button. In addition, I set up an AR display component for both input markers and added a text box under the AR display component. When the user occludes the input marker, the script will be called to display the occluded information on the AR display component. Therefore, users can easily view the information they have entered.

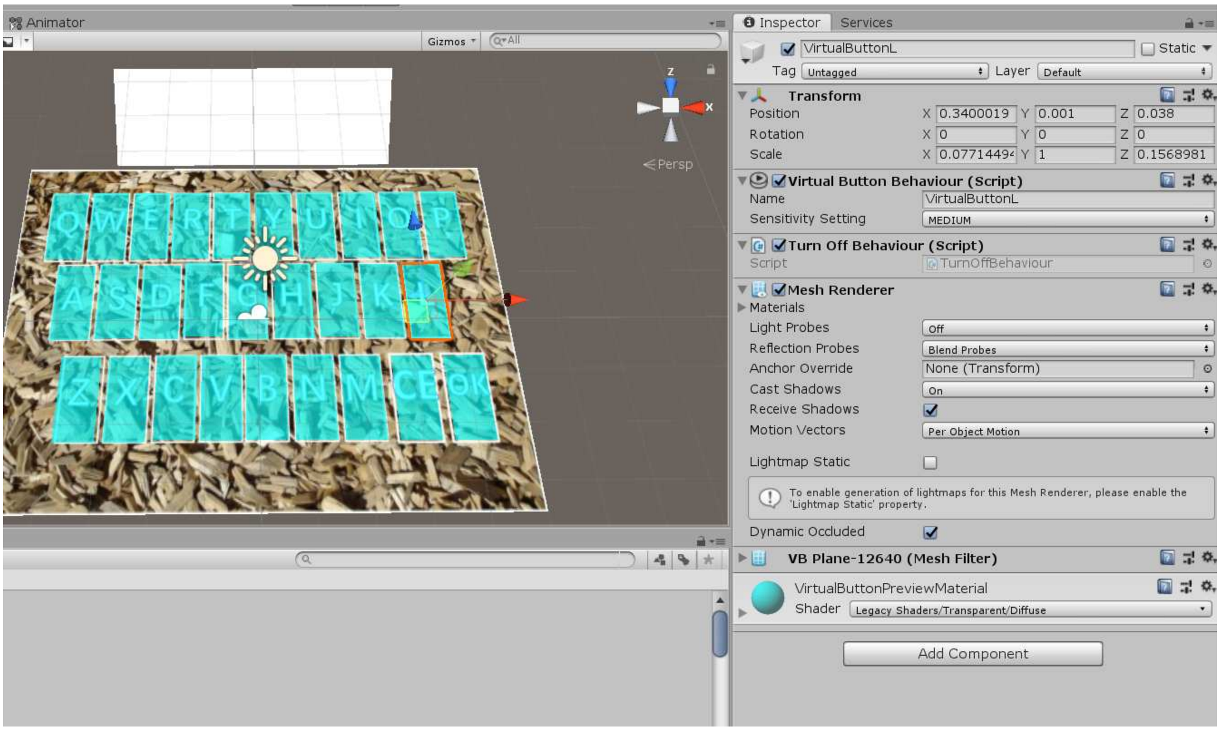

Figure 4.17 Virtual button area on the keyboard input marker.

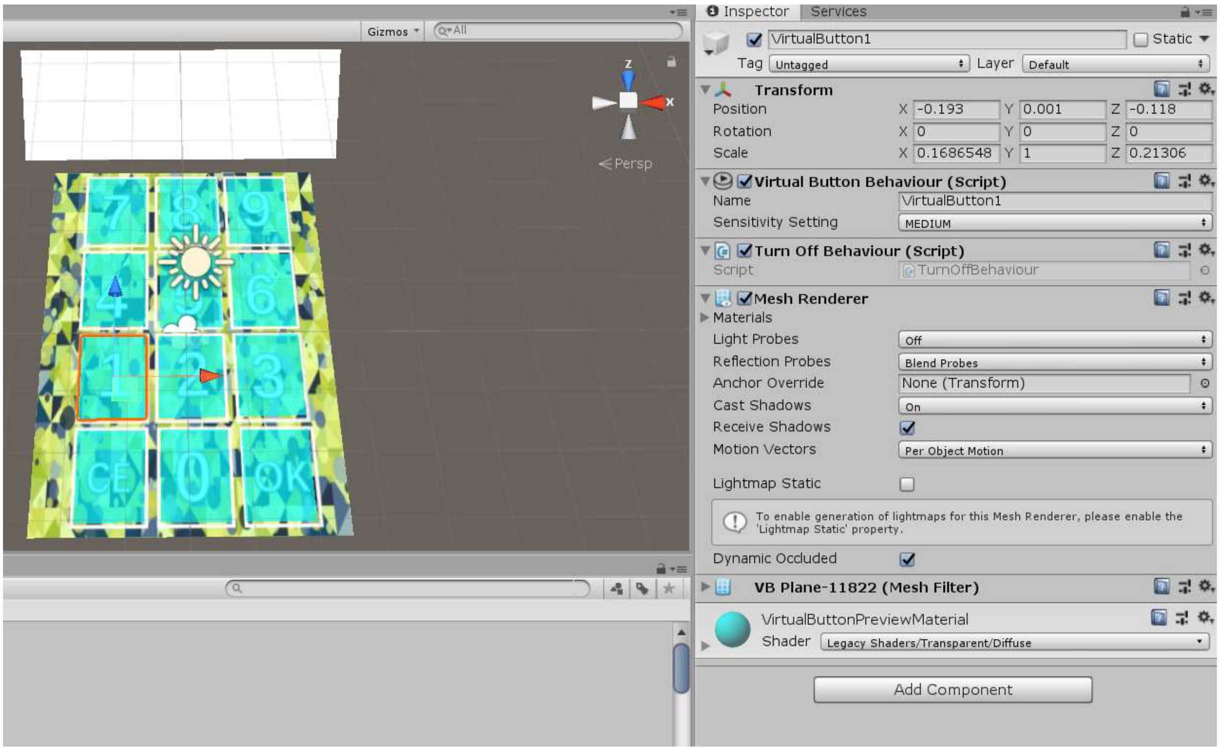

Figure 4.18 Virtual button area on the number input marker.

Occlusion problem

The system adopts a method based on feature point image recognition to determine the user's input information. Because the user's palm usually has a certain size, unnecessary occlusion problems may occur, which may cause misinput of the system (see Figure 4.19). To solve this problem, I designed and implemented an algorithm.

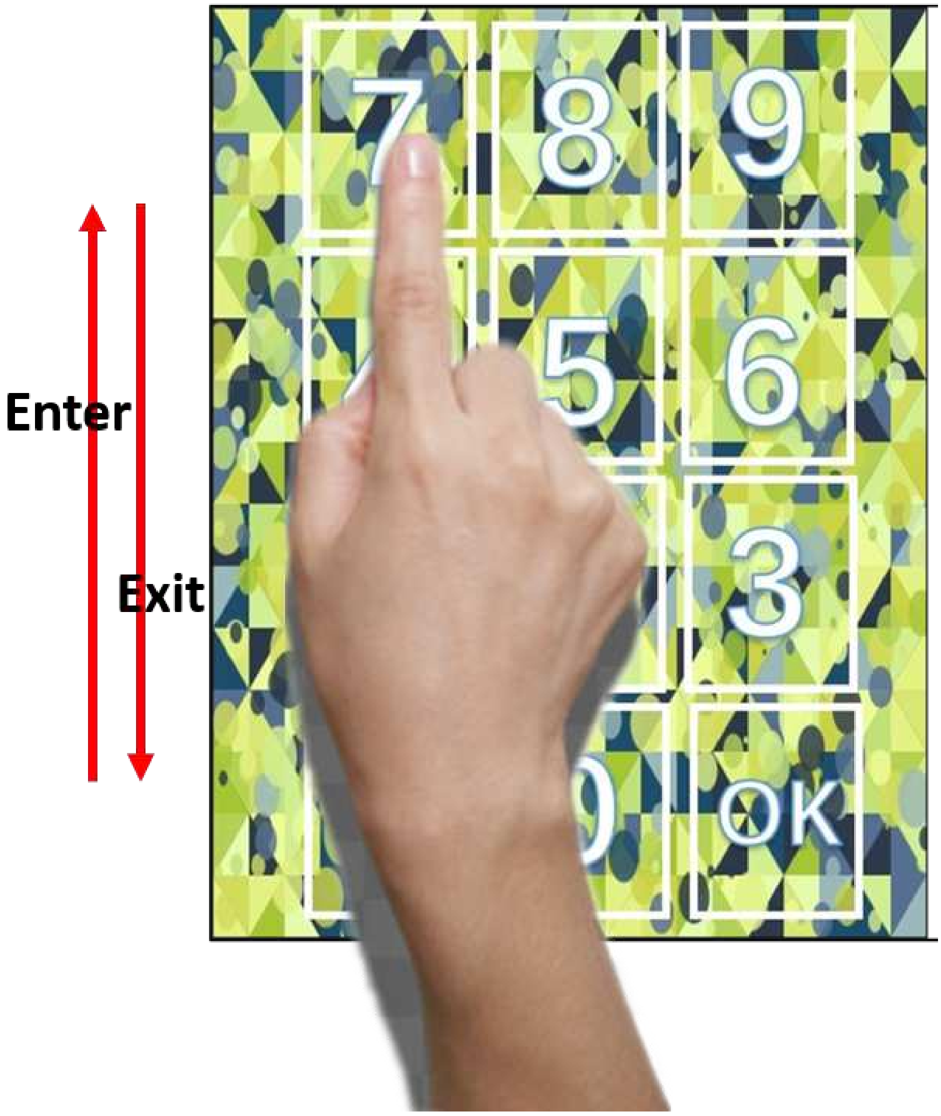

Figure 4.19 Multiple buttons blocked at the same time when the hand enters the camera field of view.

In fact, the problem of occlusion occurs when the palm enters or exits. When the palm enters the input marker from bottom to top, the palm will first cover the buttons in the lower row. But what the user needs to enter is the upper button. To solve this problem, I set a time threshold for the button. Buttons in different rows have different time thresholds, and the time thresholds of buttons in the lower row are longer than those in the upper row. In addition, I have set different priorities for buttons at different rows. The buttons on the upper row have higher priority. When the upper row button is detected to be clicked, the click information of the lower row button will be cleared.

When the user's palm enters, the lower button is touched. However, the system will not input immediately, but wait for a period of time. If the upper button is clicked within this time, the input command of the lower row button will be cleared. When the palm is withdrawn, the buttons on the upper row will first be unobstructed. I have reset the input instructions of the lower buttons when we detected the upper button input, so the lower buttons will not be input by the system when the palm is exited.

4.5.5 Virtual marker

Virtual marker modeling

I provide templates for virtual markers (see Figure 4.20). Different template markers will be used when different types of virtual markers are generated. The template markers contain two child components—one is the highlighted component and the other is the text component. The highlighted component will be displayed when the marker is selected to inform the user of the current status. The text component accepts user input and displays it. The prepared templates are saved in a prefab folder for later use.

Generating virtual marker

In the AR scenario, the status of the physical markers will be checked. When it detects that the physical markers meet a certain requirement, the system will track and record the coordinate information of the physical marker. After the system detects user input and receives the confirmed instructions, the system will dynamically generate a virtual marker according to the position of the template marker and record this virtual marker. After that, the user can perform operations on the virtual marker or continue to generate new virtual markers. For the virtual marker containing

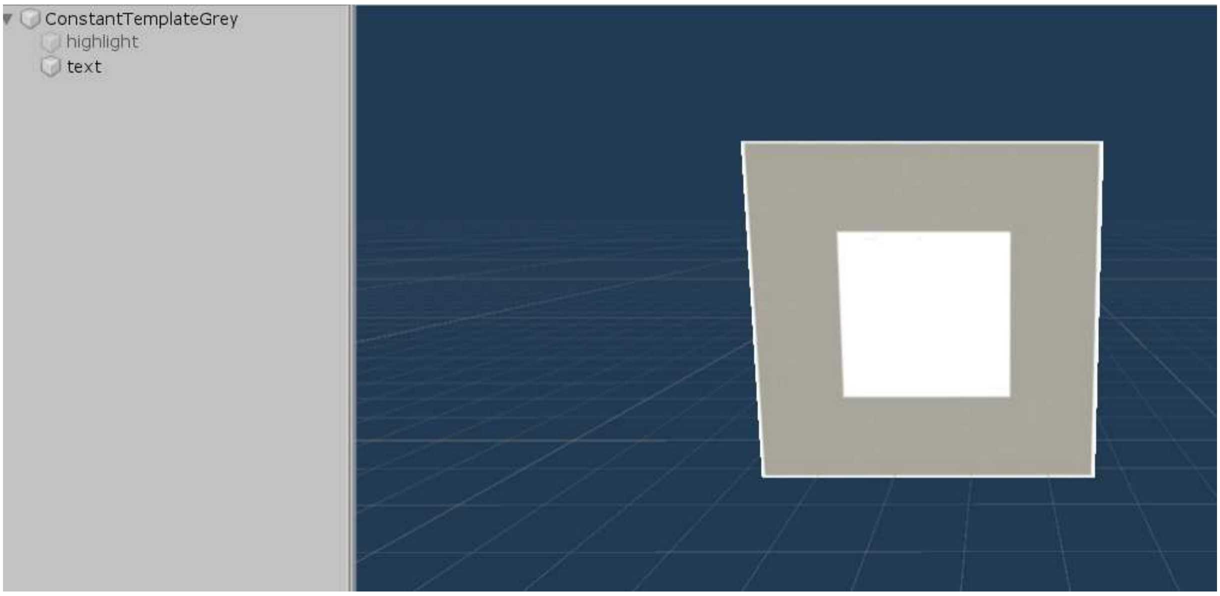

Figure 4.20 Constant virtual marker template in Unity.

combined information, I use a blank virtual marker template. The combined information will be processed according to the user's operation and presented in the text.

Manipulations of virtual marker

The user needs to first determine the virtual markers to be operated. A pointing gesture needs to be performed to determine the virtual markers. Combining the selected virtual markers with the user's real-time gesture information, the user can realize the manipulation of the virtual markers.

AR system with virtual markers

According to the position information of all the markers including the physical and virtual markers in the AR scene, we can obtain the marker sequence from Unity. Markers serve as information carriers, and their position information is used to determine the order of information combination in level 1. Therefore, the system can complete programming that combines virtual and physical markers.

In fact, the system will read all the markers in the AR scene but will not automatically establish a link between the markers. In level 2, the user selects markers and the system then establishes a connection between these markers. In level 2, the user can place the markers at any position without considering the marker sequence. This is object-oriented programming, so it has the potential to replace any component.

The processing mode of level 3 is the same as that of level 1. The user does not need to connect the markers but arrange the markers in order. The system will process the programs according to the marker sequence.

All three levels are integrated, and the system will judge the input and output based on the markers and the user's operation.

4.5.6 Hand gesture

In the system, I use leap motion as a depth sensor to track the user's hand data. Leap motion can track the position data of fingers, palms, and wrists in each frame. We can access this data and use it for gesture recognition. In order to recognize the user's gestures, we first need to classify the user's hand shape. Next, we need to access some gesture data. Combining hand shape and gesture data, we can determine the user's gesture.

4.6 Pilot Study

This chapter describes a pilot study using the proposed system. In the following sections, an outline of the experiment and detailed information on the experimenters, experiment procedures, and results are described in this order.

4.6.1 Experiment outline

Experimenters were asked to perform 2 tasks to experience the proposed system (see Figure 4.21). In the first task, they were asked to complete a designated virtual marker programming task after receiving training. The task completion time was recorded and a questionnaire survey was conducted after task 1. In the second task, they were asked to use multiple markers on their own to experience the control of AR objects. After that, I interviewed them to ask their impressions of and suggestion for the system. The purpose of the experiment was to measure the ease of use and user experience of the proposed system.

Figure 4.21 The experimenters performing tasks by themselves after training.

4.6.2 Study hypothesis

In the usability research, there are two main issues that need to be understood. In traditional marker-based systems, markers are usually physical markers. Users are accustomed to using physical markers to build AR systems. Therefore, due to the difference in usage characteristics, after the introduction of a virtual marker technique, it is necessary to better understand the user's usage and cognitive experience. Considering the certain level of system cognition required to operate the system, I put forward the first study hypothesis regarding usage experience.

Hypothesis 1 (H1). *Although the virtual marker technique will lead to changes in user usage, it will not be a significant time and operational burden to users.*

Regarding cognitive experience, I propose two experimental hypotheses.

Hypothesis 2 (H2). *The use of virtual and physical markers to establish the AR system will not reduce the user's understanding of the system and may positively increase the user's interest in using the system.*

Hypothesis 3 (H3). *The virtual marker technique can effectively expand the functions of the system and have a positive impact on users' cognitive experience.*

4.6.3 Participants

Five student volunteers (M=23) participated in the pilot study. They all have a certain background in computer science. Three volunteers have more than two years of programming experience and two have between six months and two years of experience. Four volunteers have knowledge of the marker-based system. None has ever tried to program through a marker-based system.

4.6.4 Condition and procedure

Before starting the experiment, I first explained the research purpose and experimental method to the experimenters. Next, I introduced the basic specifications of virtual marker programming, such as how to use template markers and syntax, the meaning of each marker, how to use gestures, and what kind of programs can be built. After that, the experimenters were provided with several training examples before the experiment to understand virtual marker programming. The content of examples is as follows. In these examples, the experimenters were provided with markers required for the answer in advance. I observed their operations and provided them with guidance.

Training example 1: A program that creates a virtual function marker, a virtual variable marker, and a virtual number marker.

Training example 2: A program that combines virtual and physical markers to define the first marker (If X=1).

Training example 3: A program that defines the Fibonacci function.

4.6.5 Task 1

After completing the examples, they were given the first task. The experimenters were provided with the physical markers needed for the experiment and the proposed system. They were provided with C# code on the factorial function to help them build the program (see Figure 4.22). The content of the task was displayed on the external screen, and the experimenters could browse the content of the task freely. The part of the source code that needed to use the virtual markers was marked in red, and the black part was carried or generated by the physical markers. On the PC screen, the experimenters could perform real-time operations to complete the corresponding experimental task. The system provided log information to help them use the system.

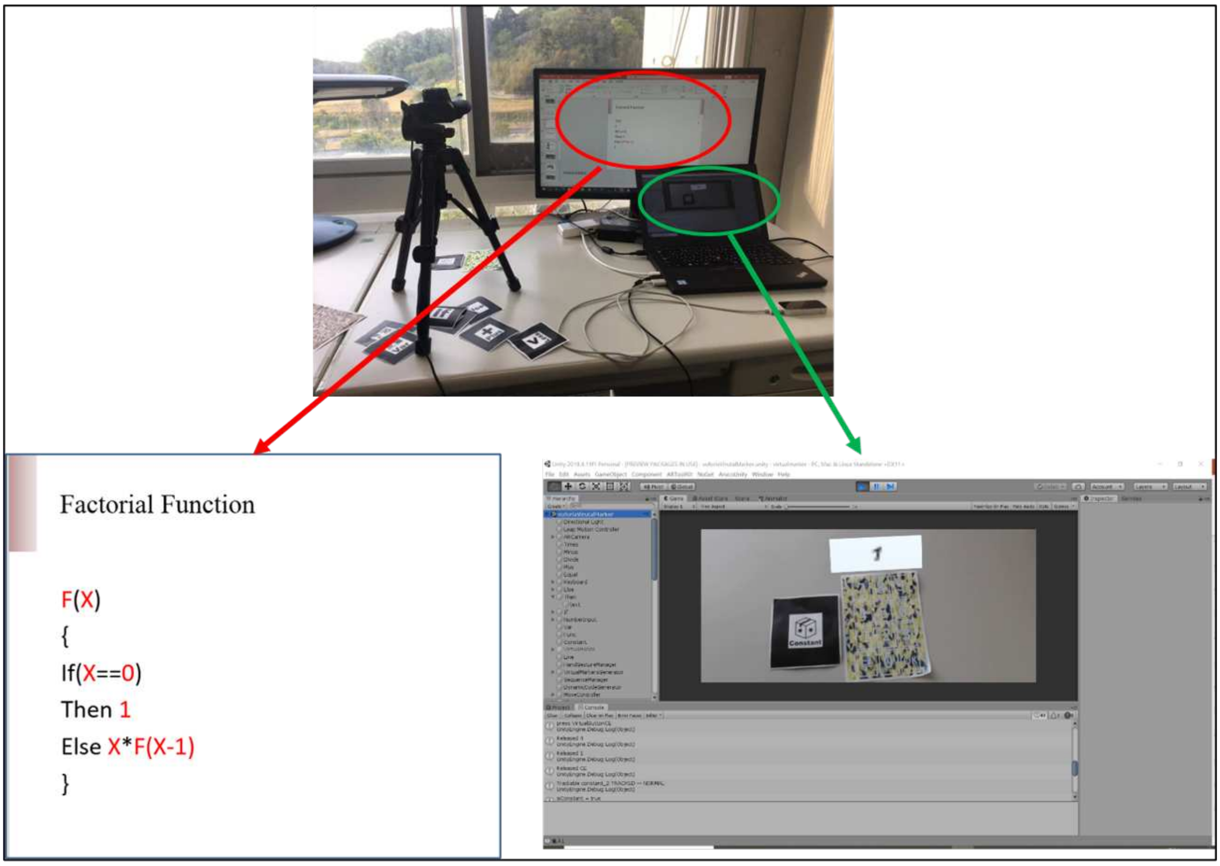

Figure 4.22 Experimenter scene for task 1. The experimenters were provided with two screens. One screen showed the task that they needed to complete, while the other screen was available for them to use the system. Other equipment in the experimental scene included a camera, a PC, leap motion, and some markers.

Task 1: A program that defines the Factorial function.

Defining the Factorial function covers several main steps, including how to create virtual markers, how to combine information, and how to use gestures. At this point, they needed to select the desired markers from all the markers and create their own program independently. The experimenters' experimental data (i.e., complete time) were recorded. After completing task 1, the experimenters took a questionnaire survey.

4.6.6 Task 2

The experimenters were introduced to how to create virtual markers containing combined information and how to control AR objects using multiple markers at first. After that, they were given two training examples to learn how to create a combined virtual marker.

Training example 4: A program that sets variable X to 10.

Training example 5: A program that combines three number markers into a 3D vector.

After completing the training, they were given a second task. I provided experimenters with a video tutorial on car control, as well as text and a picture tutorial on avatar control to guide them (see Figure 4.23). The experimenters were allowed to freely use the two screens to learn how to control the car and avatar.

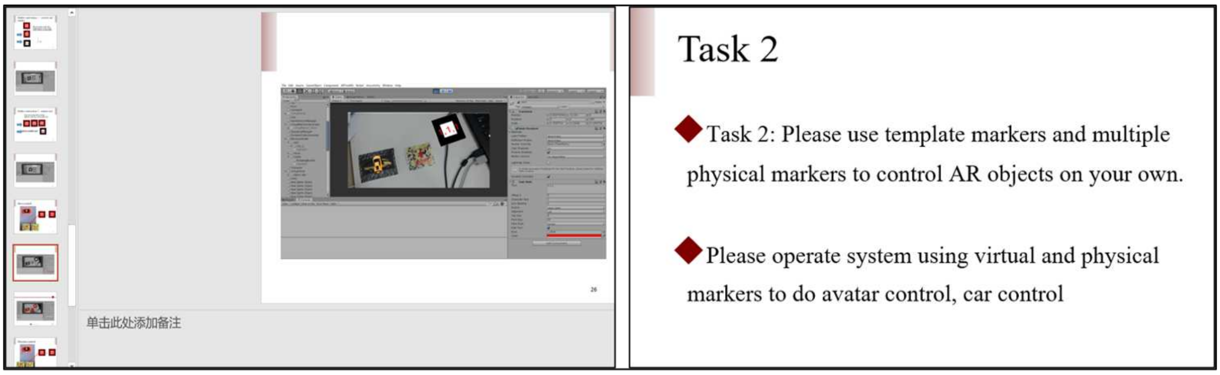

Figure 4.23 Experimenter scene for task 2. Users can freely view the video, text, and picture tutorial on the external screen. This picture shows the video tutorial and task 2 displayed on the external screen. As in task 1, the experimenters' experiment was performed on the PC screen.

Task 2: Please use template markers and physical markers to control car movement and avatar action on your own.

Their usage was recorded and they were interviewed after use to give feedback on the usage.

4.6.7 Results

Task 1 completion time

The time to complete task 1 is shown in Table 4.1. For all participants, the average completion time (sec) of task 1 was 252.2 (SD = 93.80). The researcher observed that, in the experiment, the participants' proficiency in using the system was still insufficient after the simple training was completed. The experimenters still needed to spend some time thinking about what gestures to use during the experiment. Four of the experimenters still quickly adapted to using gestures to control programming and the operation process was relatively smooth. One experimenter, P3, did not have a good grasp of how to use leap motion to capture his own gestures and complained that the gesture control of the virtual markers was complicated. On the whole, the experimenters quickly mastered the generation of virtual markers, the merging of information, and the use of gestures, and could independently complete the complex task. In fact, despite the existence of marker recognition and some time threshold setting for confirming user input to determine the input information and other external factors, most experimenters completed task 1 within a reasonable time. Considering that the experimenters could complete complicated tasks independently in a short time after only receiving simple training, I believe that this supports experimental hypothesis 1—that is, the introduction of virtual markers will not bring significant time and operational burdens to users.

Table 4.1 Task 1 completion time of each participant.

Number	Time
P1	3 minutes and 19 seconds
P2	4 minutes and 20 seconds
P3	7 minutes and 10 seconds
P4	2 minutes and 47 seconds
P5	3 minutes and 25 seconds

Questionnaire after task 1

The content and main answers of the questionnaire given to the subjects after the experiment are as follows.

Impressions about using the system

-Programming with physical and virtual markers together is very novel. (P1)

-Corresponding programming sentences can be generated through the position order relationship of the markers, which is very novel. It is also very effective to control the increase and decrease of parameters through gestures. (P2)

-The interactive method of the system is novel and interesting, which is worth trying. (P3)

-Very novel programming experience. (P4)

-Programming becomes very intuitive, which is a novel experience. (P5)

How is it different from regular programming?

-The system uses a variety of interactive methods. (P1)

-The system adds different input methods, including gestures and images, and other inputs, which is more conducive to the logical arrangement of the programmer. (P2)

-Regular programming environment focuses more on practicality, and the interactive mode of this system is more diverse. (P3)

-This system is more focused on the design of functions, the design of variables, and the relationship between variables and constants. (P4)

-The programming is divided into sentences, and the unit is spliced with markers, which is more organized. (P5)

How does it feel to use virtual markers?

-The virtual marker expands the AR marker so that the marker can be applied more flexibly. (P1)

-Overall, the system becomes more interesting. At the same time, the adjustment of virtual objects is convenient. (P2)

-Virtual markers are very creative. The relationship between virtual and physical markers can be further optimized. (P3)

-The process of creation and modification is very convenient. (P4)

-Virtual markers enable abstract codes to be flexibly spliced and manipulated, giving users a more logical and intuitive experience. (P5)

About the smooth use of the system

-The addition of gestures makes the operation of virtual markers much more convenient. (P1)

-Image detection and gesture detection with leap motion can meet the basic operations, but sometimes small errors may affect the user experience. (P2)

-I can use it more smoothly after instruction. (P3)

-At first, I was not used to the operation. But after getting familiar with the operation, I think there was no problem. (P4)

-The system can be used smoothly. The memory of gestures is a bit time-consuming. (P5)

Comments and suggestions for the system

-The operation of gestures on virtual markers is very interesting. The automatic generation of functions is very convenient. (P1)

-When the virtual marker is copied, an offset can be set for the new virtual marker. (P2)

-Whether the marker can be selected quickly has a greater impact on the user experience. The speed and accuracy of the system's response to gestures can be improved. (P3)

-The input when creating a virtual marker sometimes causes cause false touches. If this problem can be solved, I think the programming speed will be faster. The gestures used for operation require a certain amount of learning time. There may be discomfort for people who are in contact for the first time. (P4)

-The system innovatively provides an interesting programming experience, allowing users to complete programming tasks with clearer logic. At the same time, this design provides convenience for code reuse in programming. My suggestion is to improve the sensitivity and accuracy of input and design a series of gestures that are easier to remember. (P5)

From the above results, I found that all experimenters could complete task 1 independently. Moreover, I observed that in the experiment, the experimenters' order of each step was different. This shows that all experimenters had a clear personal cognitive understanding of how to use the new system. Therefore, I think that the virtual marker technique does not reduce the user's cognitive understanding of the system. Through the questionnaire survey, I found that all experimenters indicated that the system was novel in their impressions of the system. Regarding the experience of using virtual markers, all five experimenters actively expressed that it was convenient, flexible, and innovative. Based on the above, I believe that experimental hypothesis 2 is supported.

Interview after task 2

In this research, I found that the experimenters showed more understanding and interest in the second task compared to the first task. In task 2, the experimenters were allowed to explore the system freely. Although I did not record the time spent by the experimenters for task 2, I observed that the experimenters could usually complete the task of controlling the car and the character quickly (about two or three minutes each) and that most of the experimenters conducted experiments with different variants, such as generating multiple combined virtual markers to test the movement of the car in different directions. I sorted out the interviews of the experimenters after task 2 and mainly asked the experimenters to describe their feelings and opinions on the control of the car and avatar.

Q1: User experience for car control

-It is fun to control the movement of the car with the virtual and the physical markers together. The movement of the car can be realized in real-time, which is very intuitive. (P1)

-Users can adjust the position and angle of the car according to the parameters set by themselves, which is very interesting. I think it will be very convenient in future applications. (P2)

-Using virtual markers to set spatial location information is more convenient and easy to modify. The moving marker as a physical marker makes the operation more tangible, which makes me feel like I am actually driving. (P3)

-The user can customize the direction and distance of the car movement, and can operate through the physical marker. I think this is very interesting. (P4)

-The use of virtual markers is convenient for customizing the parameters of the object in the system. A marker as an entity to control the car is more interactive in physics. (P5)

Q2: User experience for avatar control

-The animation of the avatar uses a physical marker as a controller. The operation of the marker can be linked to the virtual avatar very vividly. As a user, it is easy to understand how to operate the avatar. (P1)

-Users can adjust the size of the avatar through parameters. After connecting the markers with gestures, I can also control the behavior of the avatar, which I think is very straightforward and convenient. (P2)

-The user can use the marker as the controller of the avatar action, which makes the avatar more vivid. (P3)

-A physical marker is used to control the actions of the avatar so that I am more aware of my operations. (P4)

-The marker supports passing parameters to avatar functions. At the same time, the object performs a series of actions in the real scene, so that we can experience a more intuitive effect in the system. (P5)

Q3: User experience for using virtual marker

-The virtual marker extends the function of the marker. The user can customize the parameters of the virtual marker. The interactive functions of the system have also been expanded. (P1)

-The virtual marker makes the system functions richer and easier to interact with. (P2)

-The virtual markers can be used to effectively control the parameters, and it is easy to be used in scenarios where parameter changes are required. (P3)

-The process of creating and modifying virtual markers is controlled by gestures, which are natural and intuitive. This allows me to focus on the functions and variables that need to be changed, which helps me sort out the logic. (P4)

-Controlling the parameters makes it very logical and intuitive to associate with functions and objects. (P5)

In the interview, three experimenters clearly stated that the virtual marker technique expands the function of the system and can effectively control the parameter information. Two experimenters said that after the introduction of virtual markers, the logical relationship between the markers is very clear and intuitive. Based on the above, I believe that the virtual marker technique can effectively expand the functions of the system and help users more clearly understand the connection and logic between the markers. Experimental hypothesis 3 is supported.

Q4: Comments and suggestions

Car control

-The movement of the car does not seem to be very obvious. (P1)

-The movement of the car is not very obvious on the y-axis and z-axis. (P2)

-If the car can automatically adjust the direction of the front of the car when it is moving, it will be more simulated. (P3)

-It would be better to add a turning animation. (P4)

-In addition to the movement and rotation control of the car, you can add more customizations, such as modifying the appearance and color. (P5)

Avatar control

-The animation control of the avatar is very smooth. I hope there will be more animations. (P1)

-I hope avatars can interact with real objects. (P2)

-I hope the avatar can make more actions based on the mark. This can refer to the action design of the dancing machine. (P3)

-The feedback of establishing a connection between multiple markers can be more obvious. (P4)

-I think some character effects or more interesting action language can be added. It is also good to be able to record the sound file associated with the avatar through the marker. (P5)

Virtual marker

-The gesture control of the virtual marker is very convenient. The virtual marker is powerful in multi-parameter situations, but the parameters of the virtual objects corresponding to each parameter are not clearly understood. (P1)

-I am prone to make mistakes when using virtual markers. I hope to improve this aspect to make the use more accurate. (P2)

-I think it would be better if the virtual marker shows how the parameters to be entered are used before the input. (P3)

-The need to adjust the position of the virtual marker is still a bit cumbersome. (P4)

-I think the function of adding code comments in the marker will be good. (P5)

4.7 Combine Virtual Marker With Point System

The research goal is to establish a mobile AR gamified point system based on the virtual marker technique. To provide a more attractive interactive experience, I explain how to apply virtual marker technique to improve the interaction in the gamified point system.

4.7.1 Overall structure

An AR framework is designed that combines virtual markers and physical markers to provide technical support for the point system (see Figure 4.24). Virtual markers can bring some improvements to the gamified point system.

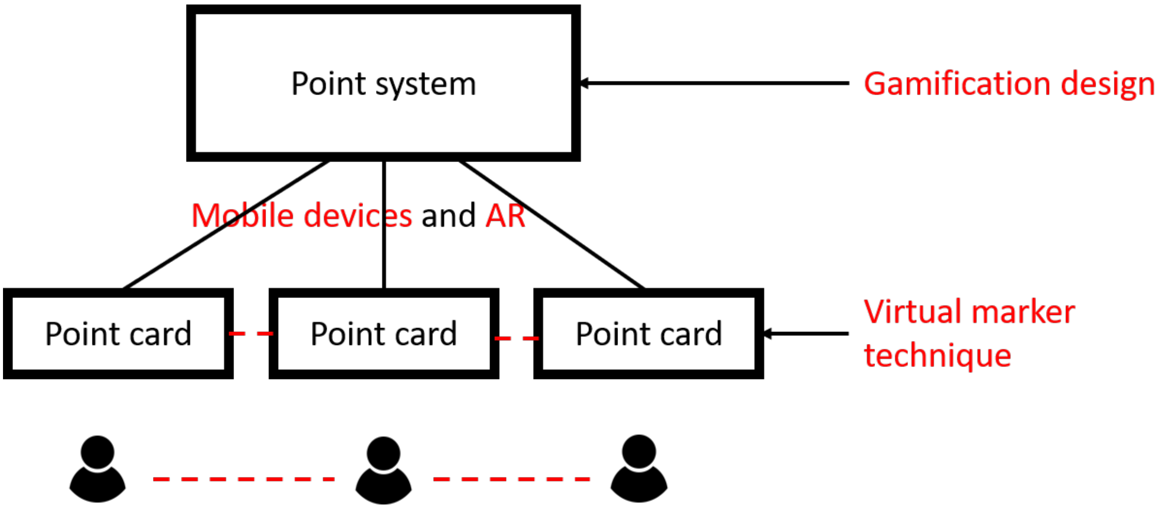

Figure 4.24 Connection between gamification design and virtual marker technique.

In the point system, the point card is the user's status symbol in the system. The point card is a bridge for users to connect to the point system. In the gamified point system, I focus on two aspects of improvement. One aspect is the improvement of the interaction between the user and the system, and the other aspect is the improvement of the social interaction between multiple users.

4.7.2 Card improvement

In the gamified point system without virtual markers, users used physical point cards to get an AR experience. In the current research, physical point cards are retained and used simultaneously with gamified point systems for AR-based interactions. This design is mainly based on the characteristics of the current point system. Because the point card is the bridge between the user and the system, I try to create a richer user experience based on the point card. Although we can use the markerless AR system to remove the need for point cards, the introduction of the point card may have meaning for the user's intuitive experience.

With the development of mobile online loyalty programs, there will be a move towards the eradication of traditional cards, in favor of an electronic equivalent. The electronic point card has no physical entity, but a virtual form of existence. Users can use physical or virtual point cards in the system based on the virtual marker technique to participate in the point system.

Figure 4.25 shows the physical point card. The physical point card has a texture on its surface. Users can view AR information through mobile devices.

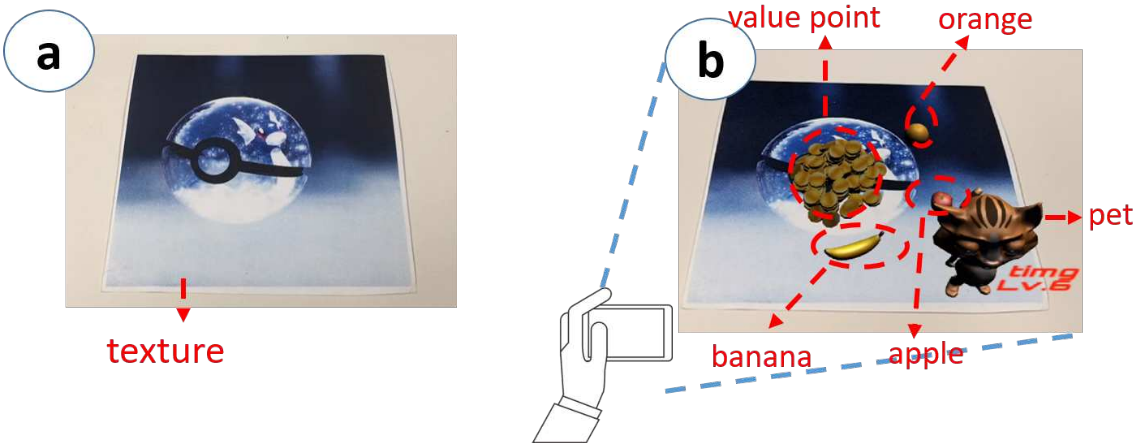

Figure 4.25 Physical point card. There is texture on the physical point card (see Figure a). Under the mobile devices, the user can see the AR information including pet, value point, and virtual food superimposed on the physical point card (see Figure b).

Figure 4.26 shows the improvement of cards. The user can create a virtual point card through the physical point card in the system. Pet-based feedback will be superimposed on the physical point card or virtual point card. Users can physical point cards or virtual point cards to interact with the system.

Figure 4.26 A virtual point card generated after touching the physical point card. Pet-based feedback is superimposed on the real point card (see Figure a). The user touches the real point card by hand directly and the card blink (see Figure b). A virtual point card with pet-based feedback is generated after touch (see Figure c).

4.7.3 Interaction with virtual pet

In the current design, the interaction between the user and the pet is limited. Users can buy virtual foods to feed their pets, increasing the energy of the pets, which is ultimately reflected in the actions of the pets. But the user cannot control the pet's behavior.

I consider using the virtual marker technique to enhance the interaction between users and pets. Users can use point cards and virtual markers to interact with their pets using programming in a way similar to level 3, such as controlling their pets to do some actions.

Figure 4.27 shows an example of the user controlling the movement of the pet by physical point card and virtual markers. The example in the figure define a function first, and then use the defined function to control the pet's movement by arranging the pet marker and the defined function marker in order.

In Figure 4.27, the defined function is that the pet will run for 3 seconds. The user can touch the leftmost point card marker to execute the program. After that, the pet will perform defined movement, and each action will be executed at a user-defined time. Users can also freely add action markers or loops to define more complex instructions.

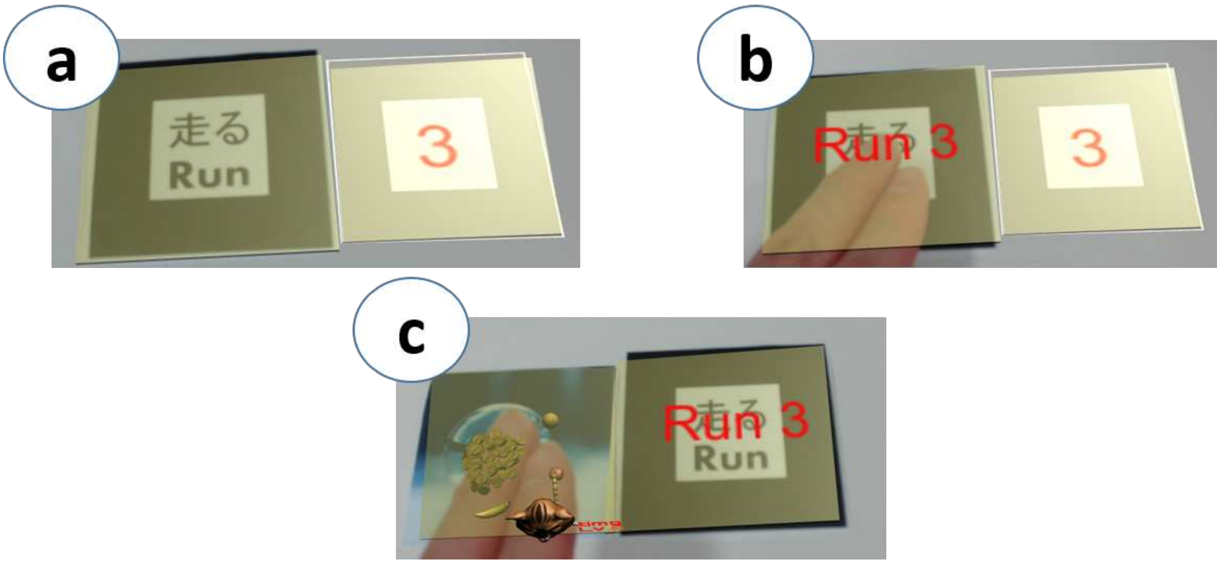

Figure 4.27 Using virtual marker programming to control the movement of the pet. When the user arranges multiple markers, the marker sequence will blink and wait for the user's touch (see Figure a). The user touches the function marker, the information will be merged into the function marker (see Figure b). The user touches the leftmost marker, the pet will run for 3 seconds (see Figure c).

Users can also interact with pets in another way (see Figure 4.28). The user can use the click on the screen to select markers to be connected. Then the user can establish the connection between the point card and the action marker containing the action instruction and control the pet's movement by clicking the action instruction area on the action marker. The user can control the pet's actions by touching on the action marker after establishing the connection between the markers. In addition, number virtual markers can be used in combination with the action marker to adjust the duration of each action.

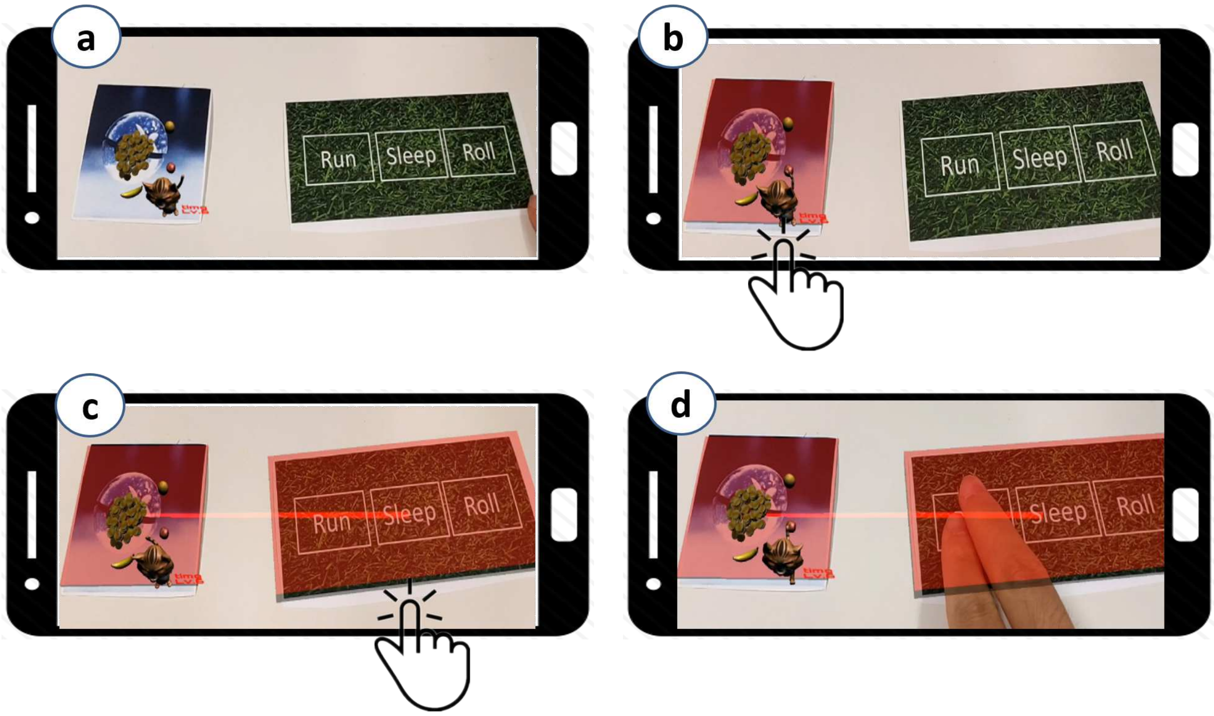

Figure 4.28 Using action marker to control the movement of the pet. The user puts the point card and the action marker under the smartphone's camera (see Figure a). The user can select the point card and action marker by clicking on the phone screen (see Figure b). After the point card or action marker is selected, red visual feedback will be provided. After two markers are selected, there will be a line between two markers to indicate they are connected (see Figure c). After they are connected, the user can touch the action marker to control the pet's actions (see Figure d).

4.7.4 Interaction with other users

Competition

The virtual marker technique can be used to improve the interaction between users. Although I provide users with different social interactions in the current design, the interaction between users is limited.

In the current competition, users can only watch the results of the competition with other users. There is no other interaction between users. The current competition interface is displayed in the form of a VR game. The environment where the pets are located in a virtual room rather than the user's real environment. In the gamified point system, other interface designs are all AR environments designed on the basis of point cards. It may be necessary to maintain consistency across all interfaces.

We can use virtual markers to provide more interaction possibilities (see Figure 4.29). Users can generate virtual point cards of their opponents in the competition and use them with their own point cards in a real environment.

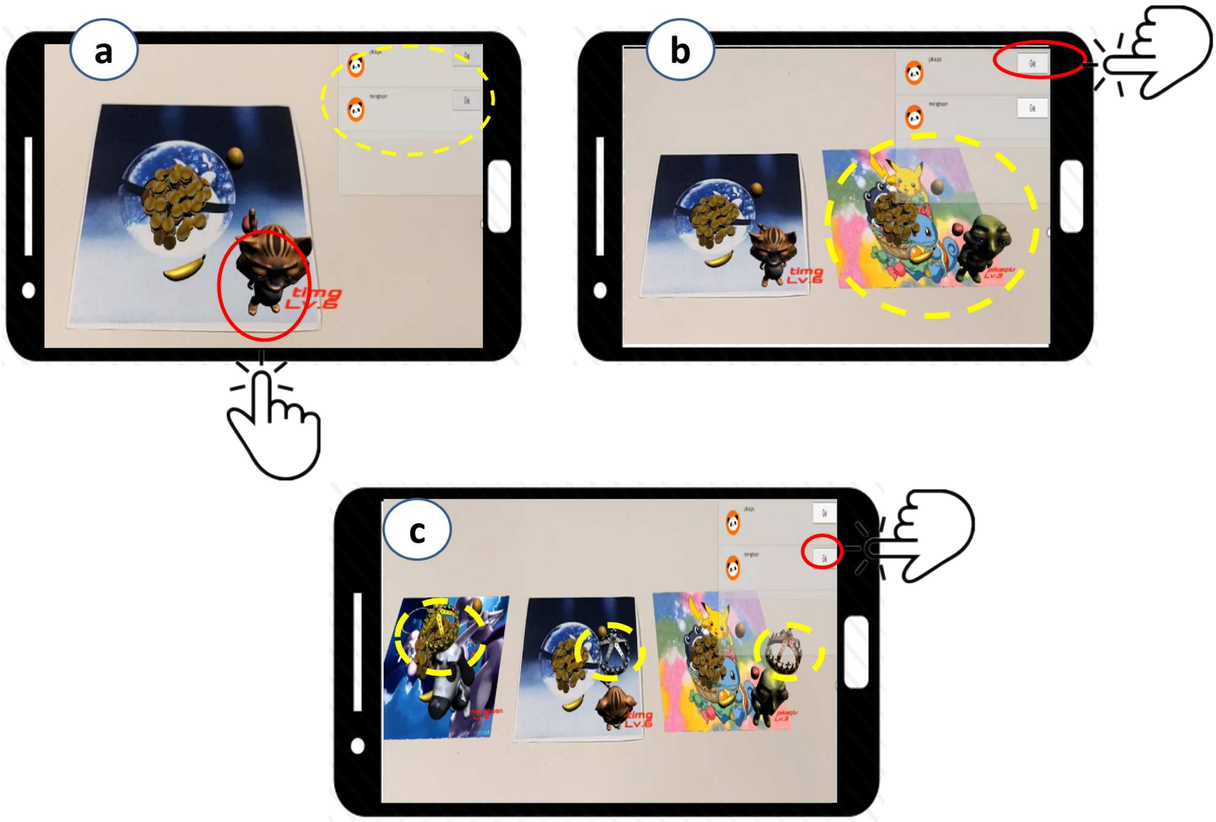

Figure 4.29 Competition based on virtual marker technique. The user clicks on the 3D model of the pet on the phone screen. The friend list will be generated on the upper right corner of the screen (see Figure a). The user clicks the button in the friend list to generate the first friend's virtual card with pet-based feedback near the user's point card (see Figure b). The user clicks the button in the friend list to generate the second friend's virtual card with pet-based feedback near the user's point card. When there are at least three users' pets, the system will automatically rank and display crowns on top of the pets according to their ranking (see Figure c).

Non-competitive interaction

In current non-competitive interactions, users can only see them giving away virtual food without any feedback. In fact, users participating in non-competitive interaction may wish to get feedback from recipients to get the joy of sharing.

The virtual marker technique can also be used to solve this problem (see Figure 4.30). Users can generate virtual point cards of the recipient and display the recipient's card and their own point cards at the same time. After the virtual food is delivered, the user can see the virtual food appearing on the recipient's virtual point card, which provides a feedback mechanism for the food giver.

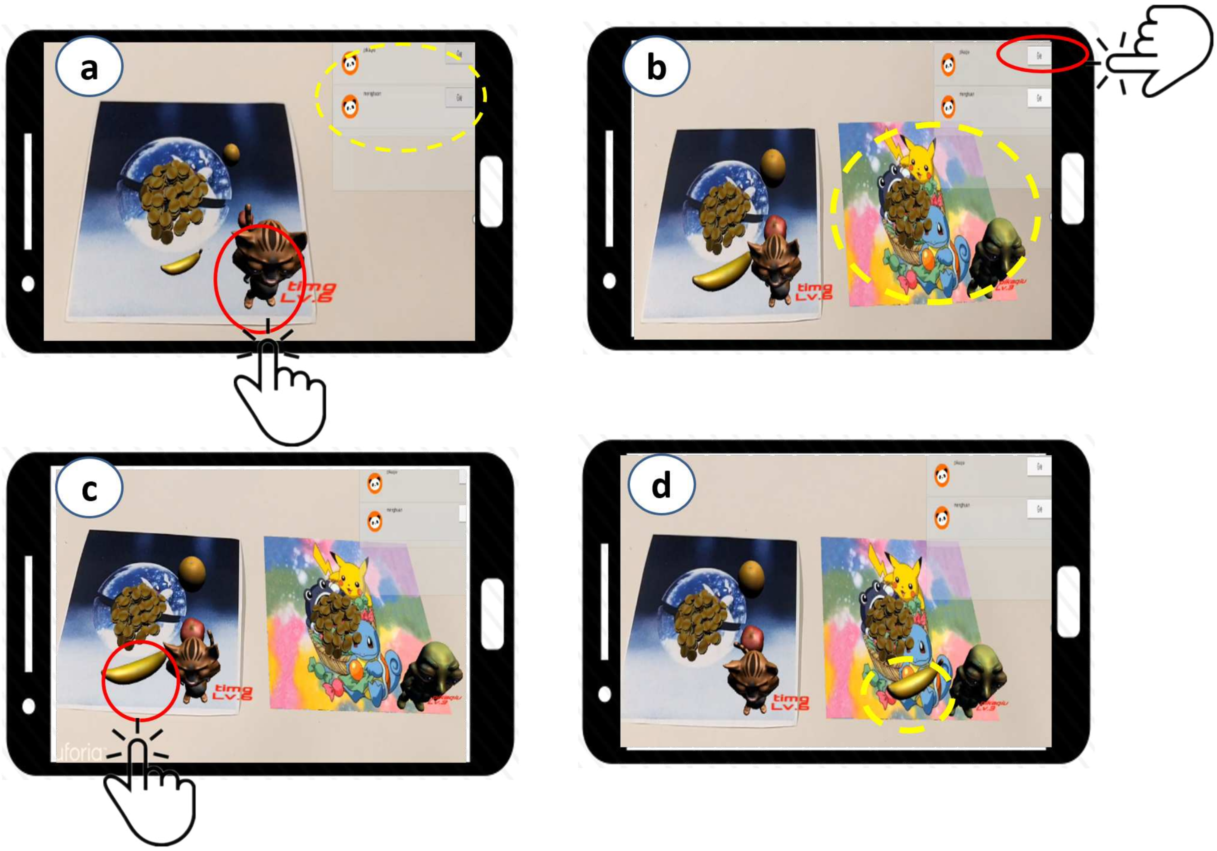

Figure 4.30 Sharing based on virtual marker technique. Value points, virtual food, and pets have pre-assigned locations. The user clicks on the 3D model of his pet on the phone screen. The friend list will be generated on the upper right corner of the screen (see Figure a). The user clicks the button in the friend list to generate his friend's virtual card with pet-based feedback near his point card (see Figure b). The user can click on the virtual food next to his pet to share it with his friends (see Figure c). The shared food will disappear from the user's own pet and appear near the friend's pet (see Figure d).

4.8 Discussion

The proposed multi-marker AR system framework with virtual markers has some advantages. In traditional marker-based AR systems, an image is registered in advance [160]. It is difficult for users to add customized information to the system. The virtual marker technique does not require pre-registration of custom information, meaning that users have the ability to freely create content. Since users are allowed to customize the information of the marker, the system becomes more flexible. In addition, due to the accuracy of this information, it can be used to perform more accurate operations on AR content.

Another technical problem in AR applications is to recognize multiple markers at the same time. Usually, it is difficult to obtain a large amount of information from multiple markers at the same time due to the need to detect feature points or special frames. The multi-marker framework solves the problem of simultaneous recognition in AR applications to a certain extent. The content of multiple markers can be integrated and stored in the first marker. The first marker can continue to be combined to incorporate more information. Therefore, the user only needs to combine the markers in batches to avoid the problem of not being able to accurately recognize multiple markers at the same time.

The preparation cost for using TUI is usually high because of the need for special equipment and tools. Previous studies have proposed a tangible programming learning environment using paper cards as objects [145, 161]. I extended such a system environment and used paper cards as physical markers. Therefore, the ease of use issues such as the hardware requirements and the acceptance of the technology have been addressed well. For the operation of virtual markers, gestures are used as methods of interaction based on previous research [162, 163].

Through a pilot study, I examined the design of the proposed system framework. I found that the introduction of virtual markers and gestures did not impose significant time and operational burdens on users. According to the user's subjective feedback on the system, they can master the system operation after basic training. Even if the experimenter, such as P3, did not noticeably improve the use of leap motion in a short time, he still affirmed the design of the system framework and took a positive attitude towards using the system.

Based on the above considerations, the design of the system meets the standards from a technical point of view and a user point of view.

4.9 Summary

In current marker-based AR systems, markers are usually independent of one other. The purpose of this research was to establish a multi-marker collaboration framework. I proposed a virtual marker technique to allow users to autonomously create and modify content. This technique allows users to correlate customized content with physical marker information and thus provide a more complete functional structure. To this end, I described several levels where this technique can be applied. I conducted a pilot study on this technique. Based on the results, I believe that this technique provides a novel and interesting interactive experience.

The virtual marker technique can be combined with the gamified point system to construct a gamified point system based on the virtual marker. The virtual marker technique expands the gamified point system from several different aspects. First, users can use physical cards or virtual cards instead of only physical cards. Second, users can generate virtual cards in the system to interact with their pets, such as controlling the movement of their pets and feeding the pets. Third, users can obtain virtual cards of other users and interact with other users' cards to get feedback from competitive and non-competitive interactions. In summary, I believe that the virtual marker technique has potential and can provide value for gamified point systems.

Chapter 5

Conclusion

5.1 Summary

In this thesis, two major studies were carried out from the user/interface design and technical perspectives – the gamification design of the AR framework (Chapter 2 and Chapter 3) and the virtual marker technique (Chapter 4).

In **Chapter 2**, I have compared AR-based 3D character design with traditional text-based design and 2D pet portrait-based design in competition design of shopping behaviors. The competition-based point system provides dynamic feedback for users' shopping. New input (i.e., mission) is added into the point system. Users obtain experience value (EXP) by completing missions while shopping and then compete in the system. I found that compared with 2D and text-based design, AR-based 3D pet design can motivate participants to complete more value creation activities in shopping. Users were willing to spend more time using AR-based 3D pet design than 2D- and text-based design and gave better questionnaire responses for AR-based 3D pet design.

In **Chapter 3**, I have explored a novel approach to integrate gamification and social interaction into a point system based on marker-based AR. My methodology includes: (1) using gamification to create frameworks that satisfy the motivations of different users and to build emotional connections between users and the system with a pet-based design. The mission design is the same as in Chapter 2. Users can complete the mission according to their own preferences. To reward the completion of a mission, new feedback is designed, including value points, pets, and virtual food. I use the same 3D pet as in Chapter 2, but the difference is that it serves as a pet instead of the user himself. The user gets value points and upgrades the level by accumulating EXP after completing the mission. Value points can be used to purchase virtual food and help pets recover energy in the system. In the end, the income, expenditure, and feeding of the pet create a positive cycle. The desire to take care of a virtual pet may facilitate and sustain the motivation for using the system, which can establish an emotional connection between the user and the system; (2) tightly coupling social impact into the point system to establish long-term connections between users. Based on these game elements, the system provides channels for interpersonal communication (i.e., competitive and non-competitive interactions), which allows users to engage in long-term interactions without binding social media. Users can interact with each other by pet-based competition or giving away virtual food in this system. Pet-based feedback was found to be effective at motivating users to participate and increasing their purchases, while the mission had a clear guiding effect on purchases. Our research proves that non-financial incentives can also be an important way to promote changes in user behavior. Social interaction positively influences the use of the system and online shopping.

In **Chapter 4**, I have proposed a virtual marker technique to build a marker-based AR system framework where multiple AR markers, including virtual and physical markers, work together. Virtual markers are generated from physical template markers or existing virtual markers. Users can completely customize these markers and use them. Therefore, such a framework has the scalability to complete more complex functions. In addition, the virtual marker technique can be used to manipulate AR objects more conveniently, which enhances the interactivity and scalability of the marker-based AR system. Multiple markers can be used as control commands as well as inputs and outputs. I have implemented a prototype system to illustrate my framework. The user can arrange multiple markers in a specific order to create a program or connect markers through hand gestures, then the result will be presented in the form of AR. I found that after the introduction of the virtual marker technique, users can still complete the task in a short period of time and show a good level of operation. In addition, users demonstrated a good cognitive understanding of the system when using the system that combines virtual and physical markers and they recommended using the system.

To conclude this thesis, I am interested in how to build an AR framework on mobile devices to promote the development of mobile e-commerce. My research explores the AR framework from several different aspects of users/interfaces and virtual content. In Chapter 2 and Chapter 3, I mainly focused on interface design and the influence of interface design on user behavior. In Chapter 4, I provided the virtual marker technique to expand the interactivity of the AR framework.

5.2 Discussion and Future Work

In future research, I plan to extend the work of **Chapter 2** by comparing the effects of different 3D characters, such as customized models and ready-made models. In the current research, I use a ready-made pet model to stimulate the user's sense of substitution. Currently, we are able to create a full-body 3D avatar from a photo and use it in applications through some SDKs. In the work of Liu et al. [164], they provided a method of human model generation, which consists of two main stages – face model generation and body model generation. Compared with ready-made pet models, the use of user-customized models may give users a stronger sense of substitution. Therefore, I consider comparing multiple different 3D characters including pet models, ready-made human models, and customized user models to study the effects of 3D characters. This may help how to build a gamified system. Currently, I use an AR display instead of the non-AR display on the mobile phone screen. Due to the novelty of AR display components, there may be differences in the impact that users receive. Comparing the same game content in the different displays (i.e., AR and non-AR) is of value to illustrate the importance of AR components in future research. These design differences may affect the user experience and become an important reason for the differences in user engagement, even if the design is a gamified system built around the same game element (e.g., competition). I plan to implement two different versions around the same game elements and 3D models in the future – the AR version and the VR version. By comparing these two versions, my goal is to explore whether AR display has design significance. Furthermore, I can compare several different AR versions to understand the meaning of AR. An example is to understand the advantages and disadvantages of remote multi-user cases and co-located cases.

For **Chapter 3**, I plan to expand the current research from several aspects in the future. The first is the diversification and personalization of missions. The system is a gamified point system for rewarding missions. Missions are designed to guide value-creating activities in shopping. It is valuable to expand the content of missions to adapt to the value needs of different people. I plan to improve the provision of missions to promote user motivation in a future study. One possible method is to create a mission list from which users can choose the mission that they are interested in. Another way is to provide personalized mission recommendations, such as considering user purchases and personal information. Users can choose characteristics before starting using the system (e.g., environmentalist or slimmer). If a user is an environmentalist, the system recommends missions related to the purchase of environmentally friendly products. If the purchase record shows that the user frequently purchases unhealthy foods, the system can give recommendations to encourage the purchase of healthy foods.

Secondly, connecting the existing gamified system to the real world is a new challenge. The current system gives users a sense of accomplishment and encourages users to create value in a manner similar to a game. How to cultivate users' awareness of value creation and allow users to continue to create value in the real world is a problem that needs to be solved in future research. I consider exploring the long-term effects of gamified systems to understand whether this change continues and has an impact on the real world. A common problem with these gamification studies is that user engagement will decrease in long-term experiments. Previous research has shown that the gamified system is used to cultivate user habits in the initial stage and therefore have a lasting impact even as time increases [34] and the downward trend was observed to be reversible with periodic updates to the game [102]. Therefore, the purpose of the gamified system is to encourage people to participate in the initial activities to the establishment of new routines. In the current research, the gamified system has been proven to change the user's shopping habits in the short term. It is meaningful to know whether users can establish new routines and maintain value creation activities during shopping. I still need to explore some issues for long-term effects. The first is how long users can maintain engagement within the current framework. Users need a certain period of participation to cultivate their behavior. If users lose their motivation to participate in a relatively short period of time, what kind of updates should I add to keep them engaged? Then, I need to observe whether users can autonomously maintain value creation activities after a period of habit training.

The design in **Chapter 4** can be further expanded in the future. The current system is based on a desktop computer. In the future, I will adjust the current framework to establish a new framework based on mobile devices. The current system uses a webcam and a leap motion as the input devices, and how to adjust the input method to adapt to mobile devices is still a task that needs to be considered. Qian et al. [165] implemented a prototype for portable 3D hand tracking using a smartphone, a leap motion controller, and a computation unit. With this method, I can use a gesture recognition method similar to that of a desktop computer to interact with the markers naturally. This may play a key role in unifying the system architecture of different platforms. With the development of mobile devices, there are in fact other alternatives. Some new mobile devices are equipped with cameras capable of capturing depth information. This improvement can be used to replace leap motion. I consider using the camera of a mobile device to recognize the gesture information of each frame and obtain 3D information through image recognition. In this way, we can only use mobile devices. However, at present, this method of recognizing gestures based on images on mobile devices still has problems such as insufficient accuracy. I believe that in the future, with the development of image recognition and other technologies, the use of mobile devices for 3D gesture operations has a bright future. In the new framework based on mobile devices, I think that the existing framework may be used to create simple AR end-user constructions. Users can write programs or modify and execute programs directly through the virtual marker technique. In the current research, the technique was applied to single-user scenarios for AR system control. I believe that this technique has the potential to be applied in multi-user scenarios. In the future, I will consider allowing the sharing of marker information recorded in the system among multiple users. This will make it possible for users to carry out division and cooperation through the system and complete the group work.

With the emergence and development of AR shopping, the e-commerce environment of AR shopping should be considered. AR shopping will no longer be limited to traditional web browsing mode and mouse and keyboard interaction. I believe that in the new e-commerce environment, 3D avatars and new interactive technologies should be valued. And social elements can be extended to the new shopping environment to provide a more comprehensive shopping experience. In general, my ultimate target is to build a gamified e-commerce environment based on mobile devices as well as AR in the future.

Bibliography

[1] Y. Chen, Q. Wang, H. Chen, X. Song, H. Tang, and M. Tian, “An overview of augmented reality technology,” in *Journal of Physics: Conference Series*, vol. 1237, no. 2. IOP Publishing, 2019, p. 022082.

[2] J. Aliprantis, M. Konstantakis, R. Nikopoulou, P. Mylonas, and G. Caridakis, “Natural interaction in augmented reality context.” in *VIPERC@ IRCDL*, 2019, pp. 50–61.

[3] D. Schmalstieg and T. Hollerer, *Augmented reality: principles and practice*. Addison-Wesley Professional, 2016.

[4] R. Azuma, “Tracking requirements for augmented reality,” *Communications of the ACM*, vol. 36, no. 7, pp. 50–51, 1993.

[5] R. T. Whitaker, C. Crampton, D. E. Breen, M. Tuceryan, and E. Rose, “Object calibration for augmented reality,” in *Computer Graphics Forum*, vol. 14, no. 3. Wiley Online Library, 1995, pp. 15–27.

[6] R. L. Holloway, “Registration errors in augmented reality systems,” Ph.D. dissertation, Citeseer, 1995.

[7] Y. Ghazwani and S. Smith, “Interaction in augmented reality: Challenges to enhance user experience,” in *Proceedings of the 2020 4th International Conference on Virtual and Augmented Reality Simulations*, 2020, pp. 39–44.

[8] M. Billinghurst, H. Kato, and S. Myojin, “Advanced interaction techniques for augmented reality applications,” in *International Conference on Virtual and Mixed Reality*. Springer, 2009, pp. 13–22.

[9] H. Kato, M. Billinghurst, I. Poupyrev, K. Imamoto, and K. Tachibana, “Virtual object manipulation on a table-top ar environment,” in *Proceedings IEEE and ACM International Symposium on Augmented Reality (ISAR 2000)*. Ieee, 2000, pp. 111–119.

[10] K. Huotari and J. Hamari, “Defining gamification: a service marketing perspective,” in *Proceeding of the 16th International Academic MindTrek Conference*. ACM, 2012, pp. 17–22.

[11] J. Koivisto and J. Hamari, “Demographic differences in perceived benefits from gamification,” *Computers in Human Behavior*, vol. 35, pp. 179–188, 2014.

[12] D. Horachek, *Creating E-Learning Games with Unity*. Packt Publishing Ltd, 2014.

[13] A. Lieberoth, “Shallow gamification: Testing psychological effects of framing an activity as a game,” *Games and Culture*, vol. 10, no. 3, pp. 229–248, 2015.

[14] J. Hamari and V. Eranti, “Framework for designing and evaluating game achievements,” *Proc. DiGRA 2011: Think Design Play*, vol. 115, no. 115, pp. 122–134, 2011.

[15] C. O’Brien, “Get ready for the decade of gamification,” *San Jose Mercury News*, vol. 24, 2010.

[16] J. D. Sutter, “Browse the web, earn points and prizes,” 2010.

[17] B. Reeves and J. L. Read, *Total engagement: How games and virtual worlds are changing the way people work and businesses compete*. Harvard Business Press, 2009.

[18] S. Deterding, “Just add points? what ux can (and cannot) learn from games,” *conftitle> Slide show presented at UX Camp Europe</conftitle>, Berlin, May*, vol. 30, 2010.

[19] J. McGonigal, *Reality is broken: Why games make us better and how they can change the world*. Penguin, 2011.

[20] M. Sicart, "Defining game mechanics," *Game Studies*, vol. 8, no. 2, pp. 1–14, 2008.

[21] S.-Y. Lee, I.-J. Kim, S. C. Ahn, H. Ko, M.-T. Lim, and H.-G. Kim, "Real time 3d avatar for interactive mixed reality," in *Proceedings of the 2004 ACM SIGGRAPH international conference on Virtual Reality continuum and its applications in industry*, 2004, pp. 75–80.

[22] P. A. Angga, W. E. Fachri, A. Elevanita, R. D. Agushinta *et al.*, "Design of chatbot with 3d avatar, voice interface, and facial expression," in *2015 International Conference on Science in Information Technology (ICSITech)*. IEEE, 2015, pp. 326–330.

[23] S.-Y. Lee, S. C. Ahn, H.-G. Kim, and M. Lim, "Real-time 3d video avatar in mixed reality: An implementation for immersive telecommunication," *Simulation & gaming*, vol. 37, no. 4, pp. 491–506, 2006.

[24] D. Jo, K.-H. Kim, and G. J. Kim, "Effects of avatar and background representation forms to co-presence in mixed reality (mr) tele-conference systems," in *SIGGRAPH ASIA 2016 virtual reality meets physical reality: modelling and simulating virtual humans and environments*, 2016, pp. 1–4.

[25] K. Tuite, N. Snavely, D.-y. Hsiao, N. Tabing, and Z. Popovic, "Photocity: training experts at large-scale image acquisition through a competitive game," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2011, pp. 1383–1392.

[26] S. Sepehr and M. Head, "Competition as an element of gamification for learning: an exploratory longitudinal investigation," in *Proceedings of the First International Conference on Gameful Design, Research, and Applications*, 2013, pp. 2–9.

[27] J.-H. Kuo, T.-H. Wu, H.-B. Ye, and H. C. Jiau, "A competitive platform for continuous programming skill enhancement," in *Proceedings of the 28th Annual International Conference on Computer Science and Software Engineering*. IBM Corp., 2018, pp. 30–39.

[28] S. Park and S. Kim, "Leaderboard design principles to enhance learning and motivation in a gamified educational environment: Development study," *JMIR Serious Games*, vol. 9, no. 2, p. e14746, 2021.

[29] T. Jagušt, I. Botički, and H.-J. So, "Examining competitive, collaborative and adaptive gamification in young learners' math learning," *Computers & education*, vol. 125, pp. 444–457, 2018.

[30] B. Morschheuser, J. Hamari, and A. Maedche, "Cooperation or competition–when do people contribute more? a field experiment on gamification of crowdsourcing," *International Journal of Human-Computer Studies*, vol. 127, pp. 7–24, 2019.

[31] T. M. Akhriza and I. D. Mumpuni, "Dartboard-like leaderboard for mapping educator career competition in a gamification system," in *2019 17th International Conference on ICT and Knowledge Engineering (ICT&KE)*. IEEE, 2019, pp. 1–5.

[32] W. Li, T. Grossman, and G. Fitzmaurice, "Cadament: a gamified multiplayer software tutorial system," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2014, pp. 3369–3378.

[33] S. Tausch, S. Ta, and H. Hussmann, "A comparison of cooperative and competitive visualizations for co-located collaboration," in *Proceedings of the 2016 CHI conference on human factors in computing systems*, 2016, pp. 5034–5039.

[34] J. J. Lin, L. Mamykina, S. Lindtner, G. Delajoux, and H. B. Strub, "Fish'n'steps: Encouraging physical activity with an interactive computer game," in *International conference on ubiquitous computing*. Springer, 2006, pp. 261–278.

[35] Z.-H. Chen and S. Y. Chen, "A surrogate competition approach to enhancing game-based learning," *ACM Transactions on Computer-Human Interaction (TOCHI)*, vol. 20, no. 6, pp. 1–24, 2013.

[36] Wikipedia contributors, "Avatar (computing) — Wikipedia, the free encyclopedia," 2021, [Online; accessed 30-June-2021]. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Avatar_(computing)&oldid=1024505525

[37] X. Wang, W. Xing, and J. M. Laffey, "Autistic youth in 3d game-based collaborative virtual learning: Associating avatar interaction patterns with embodied social presence," *British Journal of Educational Technology*, vol. 49, no. 4, pp. 742–760, 2018.

[38] A. Rollings and E. Adams, *Andrew Rollings and Ernest Adams on game design*. New Riders, 2003.

[39] Wikipedia contributors, "Digital pet — Wikipedia, the free encyclopedia," https://en.wikipedia.org/w/index.php?title=Digital_pet&oldid=1027935447, 2021, [Online; accessed 30-June-2021].

[40] Z.-H. Chen, C.-Y. Chou, Y.-C. Deng, and T.-W. Chan, "Active open learner models as animal companions: Motivating children to learn through interacting with my-pet and our-pet," *International Journal of Artificial Intelligence in Education*, vol. 17, no. 2, pp. 145–167, 2007.

[41] C. C. Liao, Z.-H. Chen, H. N. Cheng, F.-C. Chen, and T.-W. Chan, "My-mini-pet: a handheld pet-nurturing game to engage students in arithmetic practices," *Journal of Computer Assisted Learning*, vol. 27, no. 1, pp. 76–89, 2011.

[42] B. Orland, N. Ram, D. Lang, K. Houser, N. Kling, and M. Coccia, "Saving energy in an office environment: A serious game intervention," *Energy and Buildings*, vol. 74, pp. 43–52, 2014.

[43] J. Pollak, G. Gay, S. Byrne, E. Wagner, D. Retelny, and L. Humphreys, "It's time to eat! using mobile games to promote healthy eating," *IEEE Pervasive Computing*, vol. 9, no. 3, pp. 21–27, 2010.

[44] J. C. Yang, K. H. Chien, and T. C. Liu, "A digital game-based learning system for energy education: An energy conservation pet." *Turkish Online Journal of Educational Technology-TOJET*, vol. 11, no. 2, pp. 27–37, 2012.

[45] P. Jones, D. Hillier, and D. Comfort, "The sustainable development goals and business," *International Journal of Sales, Retailing and Marketing*, vol. 5, no. 2, pp. 38–48, 2016.

[46] Y.-k. Chou, *Actionable gamification: Beyond points, badges, and leaderboards*. Packt Publishing Ltd, 2019.

[47] J. K. Haas, "A history of the unity game engine," 2014.

[48] J. V. Bradley, "Complete counterbalancing of immediate sequential effects in a latin square design," *Journal of the American Statistical Association*, vol. 53, no. 282, pp. 525–528, 1958.

[49] Osman, M., "Top 10 user engagement kpis to measure," https://www.searchenginejournal.com/content-marketing-kpis/user-engagement-metrics/#close, [Online; accessed 7-April-2020].

[50] M. Altmeyer, P. Lessel, and A. Krüger, "Expense control: A gamified, semi-automated, crowd-based approach for receipt capturing," in *Proceedings of the 21st International Conference on Intelligent User Interfaces*, 2016, pp. 31–42.

[51] Boag, P., "How to measure engagement on your website and why bother," https://boagworld.com/digital-strategy/measure-engagement/, 2019, [Online; accessed 10-April-2020].

[52] B. Sharp and A. Sharp, "Loyalty programs and their impact on repeat-purchase loyalty patterns," *International journal of Research in Marketing*, vol. 14, no. 5, pp. 473–486, 1997.

[53] Greg Kihlstrom, "How customer loyalty programs can enhance the customer experience," https://www.forbes.com/sites/forbesagencycouncil/2018/11/20/how-customer-loyalty-programs-can-enhance-the-customer-experience/#25b31e735a46, 2018, [Online; accessed 25-February-2020].

[54] A. Hupfeld and C. Speed, "Getting something for nothing?: A user-centric perspective on loyalty card schemes," in *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, 2017, pp. 4443–4453.

[55] G. R. Dowling and M. Uncles, "Do customer loyalty programs really work?" *Sloan management review*, vol. 38, pp. 71–82, 1997.

[56] S. Lim and B. Lee, "Online loyalty programs viewed from a searchability perspective," in *Proceedings of the 14th Annual International Conference on Electronic Commerce*. ACM, 2012, pp. 255–262.

[57] M. Enzmann and M. Schneider, "Improving customer retention in e-commerce through a secure and privacy-enhanced loyalty system," *Information Systems Frontiers*, vol. 7, no. 4-5, pp. 359–370, 2005.

[58] Amy Gallo, "The value of keeping the right customers," https://hbr.org/2014/10/the-value-of-keeping-the-right-customers, 2014, [Online; accessed 25-February-2020].

[59] Reward Stamp, "Relationships, not rewards, are key to successful loyalty programs," https://rewardstampapp.com/traditional-card-based-vs-digital-loyalty-programs/, [Online; accessed 7-April-2020].

[60] Wikipedia contributors, "Loyalty program — Wikipedia, the free encyclopedia," https://en.wikipedia.org/w/index.php?title=Loyalty_program&oldid=946244493, 2020, [Online; accessed 6-April-2020].

[61] S. G. Magatef and E. F. Tomalieh, "The impact of customer loyalty programs on customer retention," *International Journal of Business and Social Science*, vol. 6, no. 8, pp. 78–93, 2015.

[62] B. Liu and J. Tanaka, "Ar-based point system for game-like shopping experience," in *Proceedings of the 2018 International Conference on E-Business and Applications*, 2018, pp. 41–45.

[63] B. Liu, S. Masuko, and J. Tanaka, "Interactive point system supporting point classification and spatial visualization," in *Human Interface and the Management of Information. Interaction, Visualization, and Analytics*. Springer, 06 2018, pp. 78–89.

[64] B. Liu and J. Tanaka, "Gamified point system based on mobile devices," in *The Twelfth International Conference on Advances in Computer-Human Interactions*, 2019, pp. 174–180.

[65] Digi-escape inc, "How to use a point card - the loyalty card helps you save money," https://www.digi-joho.com/living-japan/point-cards-japan.html, 2017, [Online; accessed 27-February-2020].

[66] Jayu Rewards Inc, "Traditional vs digital loyalty," http://jayurewards.com/traditional-vs-digital-loyalty/, 2020, [Online; accessed 27-February-2020].

[67] EagleEye, "Plastic vs digital loyalty cards: Which is best?" https://www.eagleeye.com/insights/blog/plastic-vs-digital-loyalty-cards-which-is-best, 2017, [Online; accessed 7-April-2020].

[68] Paula Thomas, "Stamp cards – paper or digital?" http://www.liquidbarcodes.com/still-using-stamp-cards/, 2018, [Online; accessed 7-April-2020].

[69] Kabbage, Inc, "Digital loyalty programs: Are they right for your business?" https://www.kabbage.com/resource-center/grow/digital-loyalty-programs-right-business, 2020, [Online; accessed 27-February-2020].

[70] Retail TouchPoints, "Relationships, not rewards, are key to successful loyalty programs," https://retailtouchpoints.com/resources/relationships-not-rewards-are-key-to-successful-loyalty-programs, 2014, [Online; accessed 25-February-2020].

[71] Wikipedia contributors, "Augmented reality — Wikipedia, the free encyclopedia," https://en.wikipedia.org/w/index.php?title=Augmented_reality&oldid=949464980, 2020, [Online; accessed 7-April-2020].

[72] Paul Malcolm, "The simple genius of gamification," https://vividengagement.com/the-simple-genius-of-gamification/, 2017, [Online; accessed 7-April-2020].

[73] Dewber Ltd, "Gamification and the loyalty programs," https://medium.com/@Dewber/gamification-and-the-loyalty-programs-81f40d15f897, 2018, [Online; accessed 7-April-2020].

[74] Wise Marketer Staff, "Gamification – advanced techniques to create added loyalty program engagement," https://thewisemarketer.com/channels/rewards-strategy/gamification-advanced-techniques-to-create-added-program-engagement/, 2018, [Online; accessed 7-April-2020].

[75] Ho, B., "Gamify, educate, and personalize: How to build a modern customer loyalty program," https://www.criteo.com/insights/build-a-modern-customer-loyalty-program/, 2018, [Online; accessed 7-April-2020].

[76] Brad Davis, "Why you should gamify your customer loyalty program (and how to do it)," https://www.jeffbullas.com/gamify-loyalty-program/, 2018, [Online; accessed 7-April-2020].

[77] J. Smets, G. Ergeerts, R. Beyers, F. Schrooyen, M. Ceulemans, L. Wante, and K. Renckens, "An nfc-based customer loyalty system," in *The first international conference on mobile services, resources, and user*, 2011.

[78] V. Coskun, B. Ozdenizci, K. Ok, M. Alsadi, and F. Soylemezgiller, "Design and development of nfc enabled loyalty system," in *Proceedings of the 6th international conference of advanced computer systems and networks: Design and application, Lviv, Ukraine*, 2013, pp. 16–18.

[79] A. Galletta, L. Carnevale, A. Celesti, M. Fazio, and M. Villari, "A cloud-based system for improving retention marketing loyalty programs in industry 4.0: a study on big data storage implications," *IEEE Access*, vol. 6, pp. 5485–5492, 2017.

[80] J. Hwang and L. Choi, "Having fun while receiving rewards?: Exploration of gamification in loyalty programs for consumer loyalty," *Journal of Business Research*, vol. 106, pp. 365–376, 2020.

[81] O. W. Xin, L. Zuo, H. Iida, and N. Aziz, "Gamification effect of loyalty program and its assessment using game refinement measure: Case study on starbucks," in *International Conference on Computational Science and Technology*. Springer, 2017, pp. 161–171.

[82] L. D. Hollebeek, K. Das, and Y. Shukla, "Game on! how gamified loyalty programs boost customer engagement value," *International Journal of Information Management*, p. 102308, 2021.

[83] A. Dorfman and I. Grossmann, *Social Incentives*. Cham: Springer International Publishing, 2020, pp. 5067–5070. [Online]. Available: https://doi.org/10.1007/978-3-319-24612-3_1834

[84] G.-J. Hwang, P.-H. Wu, C.-C. Chen, and N.-T. Tu, "Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations," *Interactive Learning Environments*, vol. 24, no. 8, pp. 1895–1906, 2016.

[85] Z. Bai, A. F. Blackwell, and G. Coulouris, "Exploring expressive augmented reality: The fingar puppet system for social pretend play," in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 2015, pp. 1035–1044.

[86] N. C. Bakker, J. R. da Camara, M. van Elsas, L. J. Helsloot, G. Spek, I. J. van Baar, R. Bidarra, and B. A. Kybartas, "Bloxar: augment your social life!" in *Proceedings of the first ACM SIGCHI annual symposium on Computer-human interaction in play*, 2014, pp. 319–322.

[87] C. H. Park, K. Son, J. H. Lee, and S.-H. Bae, "Crowd vs. crowd: large-scale cooperative design through open team competition," in *Proceedings of the 2013 conference on Computer supported cooperative work*. ACM, 2013, pp. 1275–1284.

[88] Wikipedia contributors, "Gamification — Wikipedia, the free encyclopedia," 2021, [Online; accessed 22-June-2021]. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Gamification&oldid=1029301649

[89] M. F. Norraji and M. S. Sunar, "warna—mobile-based augmented reality colouring book," in *2015 4th International Conference on Interactive Digital Media (ICIDM)*. IEEE, 2015, pp. 1–4.

[90] R. Bouaziz, M. Alhejaili, R. Al-Saedi, A. Mihdhar, and J. Alsarrani, "Using marker based augmented reality to teach autistic eating skills," in *2020 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*. IEEE, 2020, pp. 239–242.

[91] M. Akussah and J. Dehinbo, "Developing a marker-based handheld augmented reality application for learning mathematics," in *EdMedia+ Innovate Learning*. Association for the Advancement of Computing in Education (AACE), 2018, pp. 856–866.

[92] Q. Jin, D. Wang, X. Deng, N. Zheng, and S. Chiu, "Ar-maze: a tangible programming tool for children based on ar technology," in *Proceedings of the 17th ACM Conference on Interaction Design and Children*, 2018, pp. 611–616.

[93] Wikipedia contributors, "Pokémon go — Wikipedia, the free encyclopedia," https://en.wikipedia.org/w/index.php?title=Pok%C3%A9mon_Go&oldid=948805425, 2020, [Online; accessed 7-April-2020].

[94] C. Allen, J. Pragantha, and D. A. Haris, "3d virtual pet game" moar" with augmented reality to simulate pet raising scenario on mobile device," in *2014 International Conference on Advanced Computer Science and Information System*. IEEE, 2014, pp. 414–419.

[95] R. Wetzel, R. McCall, A.-K. Braun, and W. Broll, "Guidelines for designing augmented reality games," in *Proceedings of the 2008 Conference on Future Play: Research, Play, Share*, 2008, pp. 173–180.

[96] Wikipedia contributors, "Unity (game engine) — Wikipedia, the free encyclopedia," https://en.wikipedia.org/w/index.php?title=Unity_(game_engine)&oldid=949330256, 2020, [Online; accessed 7-April-2020].

[97] Exit Games, "Pun - photon engine," https://www.photonengine.com/pun, 2020, [Online; accessed 28-February-2020].

[98] United Nations and KPMG, "sdg industry matrix - sustainable development," https://sustainabledevelopment.un.org/content/documents/9786CRT046599%20SDG_Food_Bev_24Feb_WEB_FINAL.pdf, [Online; accessed 7-April-2020].

[99] Wikipedia contributors, "Repeated measures design — Wikipedia, the free encyclopedia," https://en.wikipedia.org/w/index.php?title=Repeated_measures_design&oldid=946897494, 2020, [Online; accessed 9-April-2020].

[100] H. Kreis and A. Mafael, "The influence of customer loyalty program design on the relationship between customer motives and value perception," *Journal of Retailing and Consumer Services*, vol. 21, no. 4, pp. 590–600, 2014.

[101] M. Marshall and S. Harrison, "It's about more than money: financial incentives and internal motivation," 2005.

[102] Z. Zhao, A. Arya, A. Whitehead, G. Chan, and S. A. Etemad, "Keeping users engaged through feature updates: A long-term study of using wearable-based exergames." in *CHI*, 2017, pp. 1053–1064.

[103] A. O. Alkhamisi, S. Arabia, M. M. Monowar *et al.*, "Rise of augmented reality: Current and future application areas," *International journal of internet and distributed systems*, vol. 1, no. 04, p. 25, 2013.

[104] H.-Y. Chang, H.-K. Wu, and Y.-S. Hsu, "Integrating a mobile augmented reality activity to contextualize student learning of a socioscientific issue," *British Journal of Educational Technology*, vol. 44, no. 3, pp. E95–E99, 2013.

[105] M. Billinghurst and A. Duenser, "Augmented reality in the classroom," *Computer*, vol. 45, no. 7, pp. 56–63, 2012.

[106] S. C.-Y. Yuen, G. Yaoyuneyong, and E. Johnson, "Augmented reality: An overview and five directions for ar in education," *Journal of Educational Technology Development and Exchange (JETDE)*, vol. 4, no. 1, p. 11, 2011.

[107] D. W. Roberts, J. W. Strohbehn, J. F. Hatch, W. Murray, and H. Kettenberger, "A frameless stereotaxic integration of computerized tomographic imaging and the operating microscope," *Journal of neurosurgery*, vol. 65, no. 4, pp. 545–549, 1986.

[108] M. Bajura, H. Fuchs, and R. Ohbuchi, "Merging virtual objects with the real world: Seeing ultrasound imagery within the patient," *ACM SIGGRAPH Computer Graphics*, vol. 26, no. 2, pp. 203–210, 1992.

[109] T. Blum, R. Stauder, E. Euler, and N. Navab, "Superman-like x-ray vision: Towards brain-computer interfaces for medical augmented reality," in *2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, 2012, pp. 271–272.

[110] S. Paszkiel, "Augmented reality of technological environment in correlation with brain computer interfaces for control processes," in *Recent Advances in Automation, Robotics and Measuring Techniques*. Springer, 2014, pp. 197–203.

[111] P. Milgram, A. Rastogi, and J. J. Grodski, "Telerobotic control using augmented reality," in *Proceedings 4th IEEE International Workshop on Robot and Human Communication*. IEEE, 1995, pp. 21–29.

[112] L. Z. W. Tang, K. S. Ang, M. Amirul, M. B. M. Yusoff, C. K. Tng, M. D. B. M. Alyas, J. G. Lim, P. K. Kyaw, and F. Folianto, "Augmented reality control home (arch) for disabled and elderlies," in *2015 IEEE Tenth international conference on intelligent sensors, sensor networks and information processing (ISSNIP)*. IEEE, 2015, pp. 1–2.

[113] G. Reinhart and C. Patron, "Integrating augmented reality in the assembly domain-fundamentals, benefits and applications," *CIRP Annals*, vol. 52, no. 1, pp. 5–8, 2003.

[114] A. Tang, C. Owen, F. Biocca, and W. Mou, "Comparative effectiveness of augmented reality in object assembly," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, 2003, pp. 73–80.

[115] H.-K. Wu, S. W.-Y. Lee, H.-Y. Chang, and J.-C. Liang, "Current status, opportunities and challenges of augmented reality in education," *Computers & education*, vol. 62, pp. 41–49, 2013.

[116] R. T. Azuma, "A survey of augmented reality," *Presence: Teleoperators and virtual environments*, vol. 6, no. 4, pp. 355–385, 1997.

[117] J. Keil, D. Edler, and F. Dickmann, "Preparing the hololens for user studies: an augmented reality interface for the spatial adjustment of holographic objects in 3d indoor environments," *KN-Journal of Cartography and Geographic Information*, vol. 69, no. 3, pp. 205–215, 2019.

[118] M. Mekni and A. Lemieux, "Augmented reality: Applications, challenges and future trends," *Applied Computational Science*, vol. 20, pp. 205–214, 2014.

[119] B. Furht, *Handbook of augmented reality*. Springer Science & Business Media, 2011.

[120] D. Van Krevelen and R. Poelman, "A survey of augmented reality technologies, applications and limitations," *International journal of virtual reality*, vol. 9, no. 2, pp. 1–20, 2010.

[121] C. Trepkowski, D. Eibich, J. Maiero, A. Marquardt, E. Kruijff, and S. Feiner, "The effect of narrow field of view and information density on visual search performance in augmented reality," in *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 2019, pp. 575–584.

[122] J. Xiong, G. Tan, T. Zhan, and S.-T. Wu, "Breaking the field-of-view limit in augmented reality with a scanning waveguide display," *OSA Continuum*, vol. 3, no. 10, pp. 2730–2740, 2020.

[123] B. Nuernberger, E. Ofek, H. Benko, and A. D. Wilson, "Snaptoreality: Aligning augmented reality to the real world," in *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 2016, pp. 1233–1244.

[124] J. Carmigniani, B. Furht, M. Anisetti, P. Ceravolo, E. Damiani, and M. Ivkovic, "Augmented reality technologies, systems and applications," *Multimedia tools and applications*, vol. 51, no. 1, pp. 341–377, 2011.

[125] M. Billinghurst, A. Clark, and G. Lee, "A survey of augmented reality," 2015.

[126] M. Billinghurst, H. Kato, I. Poupyrev *et al.*, "Tangible augmented reality," *Acm siggraph asia*, vol. 7, no. 2, pp. 1–10, 2008.

[127] H. Regenbrecht, G. Baratoff, and M. Wagner, "A tangible ar desktop environment," *Computers & graphics*, vol. 25, no. 5, pp. 755–763, 2001.

[128] M. Billinghurst, T. Piumsomboon, and H. Bai, "Hands in space: Gesture interaction with augmented-reality interfaces," *IEEE computer graphics and applications*, vol. 34, no. 1, pp. 77–80, 2014.

[129] M.-T. Yang and W.-C. Liao, "Computer-assisted culture learning in an online augmented reality environment based on free-hand gesture interaction," *IEEE Transactions on Learning Technologies*, vol. 7, no. 2, pp. 107–117, 2014.

[130] D. R. Berryman, "Augmented reality: a review," *Medical reference services quarterly*, vol. 31, no. 2, pp. 212–218, 2012.

[131] K. Martin Sagayam, C. C. Ho, L. Henesey, and R. Bestak, "3d scenery learning on solar system by using marker based augmented reality," in *4th International Conference of the Virtual and Augmented Reality in Education, VARE 2018; Budapest*. Dime University of Genoa, 2018, pp. 139–143.

[132] P. Q. Brito and J. Stoyanova, “Marker versus markerless augmented reality. which has more impact on users?” *International Journal of Human–Computer Interaction*, vol. 34, no. 9, pp. 819–833, 2018.

[133] S. Steiniger, M. Neun, and A. Edwardes, “Foundations of location based services,” *Lecture Notes on LBS*, vol. 1, no. 272, p. 2, 2006.

[134] A. Katiyar, K. Kalra, and C. Garg, “Marker based augmented reality,” *Advances in Computer Science and Information Technology (ACSIT)*, vol. 2, no. 5, pp. 441–445, 2015.

[135] D. Wagner, T. Pintaric, F. Ledermann, and D. Schmalstieg, “Towards massively multi-user augmented reality on handheld devices,” in *International Conference on Pervasive Computing*. Springer, 2005, pp. 208–219.

[136] A. K. Dash, S. K. Behera, D. P. Dogra, and P. P. Roy, “Designing of marker-based augmented reality learning environment for kids using convolutional neural network architecture,” *Displays*, vol. 55, pp. 46–54, 2018.

[137] M. S. Horn, E. T. Solovey, R. J. Crouser, and R. J. Jacob, “Comparing the use of tangible and graphical programming languages for informal science education,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2009, pp. 975–984.

[138] D. Amin and S. Govilkar, “Comparative study of augmented reality sdks,” *International Journal on Computational Science & Applications*, vol. 5, no. 1, pp. 11–26, 2015.

[139] T.-W. Kan, C.-H. Teng, and M. Y. Chen, “Qr code based augmented reality applications,” in *Handbook of augmented reality*. Springer, 2011, pp. 339–354.

[140] A. L. L. Sing, A. A. A. Ibrahim, N. G. Weng, M. Hamzah, and W. C. Yung, “Design and development of multimedia and multi-marker detection techniques in interactive augmented reality colouring book,” in *Computational Science and Technology*. Springer, 2020, pp. 605–616.

[141] P. Boonbrahm, C. Kaewrat, and S. Boonbrahm, "Effective collaborative design of large virtual 3d model using multiple ar markers," *Procedia Manufacturing*, vol. 42, pp. 387–392, 2020.

[142] H. Zeng, X. He, and H. Pan, "Funpianoar: a novel ar application for piano learning considering paired play based on multi-marker tracking," in *Journal of Physics: Conference Series*, vol. 1229, no. 1. IOP Publishing, 2019, p. 012072.

[143] K. Hattori and T. Hirai, "An intuitive and educational programming tool with tangible blocks and ar," in *ACM SIGGRAPH 2019 Posters*, 2019, pp. 1–2.

[144] I. Radu and B. MacIntyre, "Augmented-reality scratch: a tangible programming environment for children," in *Proceedings of conference on interaction design for children, Como, Italy*, 2009.

[145] K. Tada and J. Tanaka, "Tangible programming environment using paper cards as command objects," *Procedia Manufacturing*, vol. 3, pp. 5482–5489, 2015.

[146] K. Tada, S. Takahashi, and B. Shizuki, "Smart home cards: tangible programming with paper cards," in *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*, 2016, pp. 381–384.

[147] H. Park and J.-I. Park, "Invisible marker tracking for ar," in *Third IEEE and ACM International Symposium on Mixed and Augmented Reality*. IEEE, 2004, pp. 272–273.

[148] ——, "Invisible marker based augmented reality system," in *Visual Communications and Image Processing 2005*, vol. 5960. International Society for Optics and Photonics, 2005, p. 59601I.

[149] ——, "Invisible marker–based augmented reality," *Intl. Journal of Human–Computer Interaction*, vol. 26, no. 9, pp. 829–848, 2010.

[150] C. Kuo, T. Jeng, and I. Yang, "An invisible head marker tracking system for indoor mobile augmented reality," *Automation in construction*, vol. 33, pp. 104–115, 2013.

[151] Y. Nakazato, M. Kanbara, and N. Yokoya, "Discreet markers for user localization," in *Eighth International Symposium on Wearable Computers*, vol. 1. IEEE, 2004, pp. 172–173.

[152] J. Häkkilä, J. Rantakari, L. Virtanen, A. Colley, and K. Cheverst, "Projected fiducial markers for dynamic content display on guided tours," in *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, 2016, pp. 2490–2496.

[153] H. Tobita, "Aero-marker: blimp-based augmented reality marker for objects with virtual and tangible features," in *Proceedings of the 12th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and Its Applications in Industry*, 2013, pp. 223–230.

[154] R. L. Peiris, O. N. N. Fernando, and A. D. Cheok, "A dynamic ar marker for a paper based temperature sensor," in *International Joint Conference on Ambient Intelligence*. Springer, 2011, pp. 195–199.

[155] J. Kobylarz, J. J. Bird, D. R. Faria, E. P. Ribeiro, and A. Ekárt, "Thumbs up, thumbs down: non-verbal human-robot interaction through real-time emg classification via inductive and supervised transductive transfer learning," *Journal of Ambient Intelligence and Humanized Computing*, vol. 11, no. 12, pp. 6021–6031, 2020.

[156] Wikipedia contributors, "Gesture recognition — Wikipedia, the free encyclopedia," https://en.wikipedia.org/w/index.php?title=Gesture_recognition&oldid=1031222577, 2021, [Online; accessed 3-July-2021].

[157] M. Lee, R. Green, and M. Billinghurst, "3d natural hand interaction for ar applications," in *2008 23rd International Conference Image and Vision Computing New Zealand*. IEEE, 2008, pp. 1–6.

[158] A. Bellarbi, S. Benbelkacem, N. Zenati-Henda, and M. Belhocine, “Hand gesture interaction using color-based method for tabletop interfaces,” in *2011 IEEE 7th International Symposium on Intelligent Signal Processing*. IEEE, 2011, pp. 1–6.

[159] C. Lu, B. Liu, and J. Tanaka, “Implementing hand gestures for a room-scale virtual reality shopping system,” *International Journal on Advances in Software Volume 12, Number 3 & 4, 2019*, 2019.

[160] Wikipedia contributors, “Augmented reality — Wikipedia, the free encyclopedia,” 2021, [Online; accessed 2-May-2021]. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Augmented_reality&oldid=1020615451

[161] T. Shelley, L. Lyons, M. Zellner, and E. Minor, “Evaluating the embodiment benefits of a paper-based tui for educational simulations,” in *CHI’11 Extended Abstracts on Human Factors in Computing Systems*, 2011, pp. 1375–1380.

[162] H. Bai, L. Gao, J. El-Sana, and M. Billinghurst, “Markerless 3d gesture-based interaction for handheld augmented reality interfaces,” in *2013 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, 2013, pp. 1–6.

[163] M.-T. Yang, W.-C. Liao, and Y.-C. Shih, “Vecar: Virtual english classroom with markerless augmented reality and intuitive gesture interaction,” in *2013 IEEE 13th International Conference on Advanced Learning Technologies*. IEEE, 2013, pp. 439–440.

[164] Y. Liu, Y. Liu, S. Xu, K. Cheng, S. Masuko, and J. Tanaka, “Comparing vr-and ar-based try-on systems using personalized avatars,” *Electronics*, vol. 9, no. 11, p. 1814, 2020.

[165] J. Qian, J. Ma, X. Li, B. Attal, H. Lai, J. Tompkin, J. F. Hughes, and J. Huang, “Portalble: Intuitive free-hand manipulation in unbounded smartphone-based augmented reality,” in *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*, 2019, pp. 133–145.

Publication list

<Journal>

[1] Boyang Liu and Jiro Tanaka, "Virtual Marker Technique to Enhance User Interactions in a Marker-based AR System," Applied Sciences, 11, 4379, 25 pages, May 2021. DOI:10.3390/app11104379

[2] Boyang Liu and Jiro Tanaka, "Integrating Gamification and Social Interaction into an AR-Based Gamified Point System," Multimodal Technologies and Interaction, 4(3), 51, 19 pages, August 2020. DOI:10.3390/mti4030051

[3] Chunmeng Lu, Boyang Liu, and Jiro Tanaka, "Implementing Hand Gestures for a Room-scale Virtual Reality Shopping System," International Journal on Advances in Software, Vol.12, No. 3&4, pp.216-227, December 2019.

<International conference>

[1] Boyang Liu and Jiro Tanaka, "Applying Social Gamification in a Gamified Point System," The 22nd International Conference on Human-Computer Interaction (HCII 2020), Denmark, LNCS 12211, pp.148-161, July 2020. (Acceptance rate: 26.5%) DOI:10.1007/978-3-030-50164-8_10

[2] Zhinan Li, Ruichen Ma, Kohei Obuchi, Boyang Liu, Kelvin Cheng, Soh Masuko, and Jiro Tanaka, "Augmented Reality Shopping System through Image Search and Virtual Shop Generation," The 22nd International Conference on Human-Computer Interaction (HCII 2020), Denmark, LNCS 12184 , pp.363-376, July 2020. (Acceptance rate: 26.5%) DOI:10.1007/978-3-030-50020-7_26

[3] Shihui Xu, Bo Yang, Boyang Liu, Kelvin Cheng, Soh Masuko, and Jiro Tanaka, "Sharing Augmented Reality Experience between HMD and non-HMD user," The 21st International Conference on Human-Computer Interaction (HCII 2019), USA, LNCS 11570, pp.187-202, Aug 2019. (Acceptance rate: 29.5%) DOI:10.1007/978-3-030-22649-7_16

[4] Boyang Liu and Jiro Tanaka, "Gamified Point System Based On Mobile Devices," The Twelfth International Conference on Advances in Computer-Human Interactions (ACHI 2019), Greece, pp.174-180, Feb 2019. (Acceptance rate: 30%)

[5] Boyang Liu, Soh Masuko, and Jiro Tanaka, "Interactive Point System Supporting Point Classification and Spatial Visualization," The 20th International Conference on Human-Computer Interaction (HCII 2018), USA, LNCS 10904, pp.78-89, July 2018. (Acceptance rate: 31.2%) DOI:10.1007/978-3-319-92043-6_7

[6] Boyang Liu and Jiro Tanaka, "AR-Based Point System for Game-like Shopping Experience," 2018 International Conference on E-Business and Applications (ICEBA 2018), Vietnam, pp.41-45, Feb 2018. DOI:10.1145/3194188.3194189

<Conference without review>

[1] Boyang Liu and Jiro Tanaka, "AR-Based Gamified Point System with Pet Design," 2019 年度（第 72 回）電気・情報関係学会九州支部連合大会, 第 10 会場, International Session (2) Computer Science and Information Technologies. 10-1A-01, pp.107-108, 2019 年 9 月.

[2] Boyang Liu, Soh Masuko, Jiro Tanaka, "Gamified Point System On Mobile Device," The 12th International collaboration Symposium on Information, Production and Systems, pp.59-60, November 2018.

[3] Boyang Liu and Jiro Tanaka, "Applying augmented reality and gamification in micropayment system interface design," The 11th International collaboration Symposium on Information, Production and Systems, pp.329-332, November 2017.