Increasing the Walking Exercise Motivation Using Full-body 3D Personalized Avatar in Augmented Reality

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Abstract

We explore a future in which people spend considerably more time using Augmented Reality technology, even during moments in daily life. Walking is an easily accessible and effective exercise so that it can participate in daily life. However, due to changes the social structure such as the increase in single-person households and hectic lifestyle, increase the number of people who walk exercise alone. Meanwhile, we found the problem that people often decrease their motivation when they walk exercise alone.

We designed an Augmented Reality system for increasing users' motivation of walking exercise. According to related studies in physical activity, exercising with a partner or part of a group is positive for exercise effectiveness and motivation. Thus, we focused on the social aspect of physical exercise as a method to increase the motivation for walking exercise. Specifically, a 3D Personalized avatar is implemented as a virtual walking partner in Augmented Reality. We designed a novel interactions that user enables a realistic walking experience with a virtual walking partner. Our system has two use cases: *(1)* Walking exercise with an avatar, *(2)* Walking exercise with a remote user using an avatar. In case #1, we designed interactions between a user and a 3D avatar. And in case #2, for the simultaneous walking experience between users who are in long-distance remote locations using the 3D avatar. In this case, we designed novel method of movement synchronization between user and avatar using only the HMD without extra sensors for motion capture and record.

We investigated the effect of 3D personalized avatar in Augmented Reality as a virtual walking partner to increase the motivation of walking exercise. As a result of the preliminary evaluation of the system, most of the participants responded positively about our system. The results support the idea that novel interactions in walking exercise scenes between the user and virtual partner can increase the motivation of walking exercise. In the future, we plan to improve the system and conduct quantitative evaluations to prove the effectiveness of the system. And we will also further explore Augmented Reality technology which increases immersive user experience with a virtual partner.

Keywords: Augmented Reality, 3D Personalized Avatar, Virtual Partner, Walking Exercise

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Chapter 1

Introduction

We explore a future that people spend more time using Augmented Reality technology, even during moments in daily life. Augmented Reality is 3D digital objects that are superimposed into a 3D physical world in real time [1]. It is also a technology that can compose a virtual environment based on the physical world by synthesizing virtual graphics. Currently, new experiences are being provided through the application of Augmented Reality in various domains. We are interested in how Augmented Reality can improve the human experience in physical activity. In recent years, as awareness of people's physical and mental health is improved, people's interest and demand for physical activity is increasing as well.

We are interested in how Augmented Reality can improve the human experience in physical activity. Walking is an easily accessible and effective exercise so that it can participate in daily life. However, according to the social environment changes, e.g. increasing in single-person household and single-person activities due to changes in population and hectic lifestyle. It is not easy to find an exercise partner to be with at the desired time and place for walking exercise. In general, it is known that the effect of physical activity is more effective when performed with the group or with a partner rather than alone. In our study, we design an avatar as a virtual walking partner in Augmented Reality and novel interactions in walking exercise scenes. In this study, we investigate how our Augmented Reality system increases the user's motivation for walking exercise.

1.1 Background

Due to the changes in social structure, the majority of people who live in cities use vehicles to move for their daily life [2]. The reason why people have lack of physical activity is that lack of time or appropriate motivation [3]. In addition, with the increase in single-person households, the number of people who exercise alone is increasing. We found the issues in which people often decrease their motivation when they walking exercise alone. Thus, we design an Augmented Reality system to solve the issues in walking exercise. Our study has the background as following factors:

- **Augmented Reality in physical activity:** The use of Augmented Reality technology has been recently considered as a new approach to promoting physical activity and health behavior [4]. Augmented Reality technologies and exercise can be utilized as innovative interventions to counteract negative environmental impacts on physical activity and increase the motivation of exercise [5]. Augmented Reality is expanding not only the function of simply showing additional digital information but also the concept of extending human beings' capabilities and emotions. The application of Augmented Reality to physical activity will continue to expand in the future. In general, since people always expect more feedback than the information and data that they already have. In particular, the amount of information required is inevitably large because most of them have specific goals due to the feature of physical activity. We believe that Augmented Reality technology can be a solution that can satisfy the needs of these people. Additionally, we expect that it will be a good solution as a solution to human psychological problems such as the inevitability of boredom and indolence caused by repetitive actions such as walking exercise. In this study, we explore the effect of Augmented Reality system that increase the user's motivation of walking exercise.

- **Sense of presence in virtual 3D avatar:** The presence of realistic virtual partners could replace many roles of physical partners. Above all, virtual partners are very attractive in that they allow users to overcome the limitations of time and space.

The actual sense of presence in the avatar is an important factor in determining the effectiveness of our system for walking exercise with a virtual partner. In this study, the virtual walking partner consists of two concepts. First, the interaction with a full virtual partner, and the interaction with a virtual partner whose movement is synchronized by remote user's. We designed the form and behavior of the virtual partner to be the closest to human beings to enhance the virtual partner's real presence. Furthermore, for realistic interaction with virtual avatar and simultaneous walking experience with a long-distance remote user, the sense of presence in virtual 3D avatar needs to be improved. In addition, we consider telepresence for a simultaneous walking experience with a remote user. Telepresence is a compound word of 'Tele' meaning remote and 'Presence' meaning existence, and it is a technology that makes it appear as if they are in the same space in a distant person remotely. It is a technology that enables humans to feel in real time and interact with remote environments as if they were in a place other than where they actual exist [6]. In this study, the movement of the avatar is synchronized with the remote user in real time, so that each user can feel the sense of mutual presence. An avatar that is synchronized with the user's movements enhances the real sense of presence.

1.2 Organization of the Thesis

This thesis consist of total seven chapters: *Chapter #1*, we describe the introduction of research and background. *Chapter #2*, we introduce and analyze the related works and describe the position and differences of our study compared to the related works. *Chapter #3*, we describe the problems that we want to solve, and the purpose and approach of the study. *Chapters #4* and *Chapter #5*, we describe the details that how to design and implementation of our system to achieve the goal of the study. *Chapter #6*, we describe the preliminary evaluation and result of how effectiveness of the novel interactions and system. And we derive the discussion issues from the evaluation results. Lastly, *Chapter #7*, we describe the conclusion and future work of this study.

Chapter 2

Related Work

In this chapter, we describe the result of analyzing the related work to reveal relevance and differences with our research. We investigated the scope of related work based on the similarity of the research target, method, and technical method of implementation with this study. Since few related research have been studied, we investigated and analyzed related studies on the following subject. Our study is related to work in the following categories: Social aspects of physical exercise, Augmented Reality and Mixed Reality for motivation, interactive virtual full-body avatar and walking support in Augmented Reality.

2.1 Leverage of Social Aspects in Physical Exercise

We focused on the social aspects of physical exercise to increase the motivation of walking exercise. We designed interactions that can occur as users walk with their partners, i.e. the user can walk while cooperating and competing with a virtual walking partner. Even it is a virtual experience, but we expect that it can be provided the experience of walking with partner to the user. Hanson, S. and Jones, A.(2015) studied the motivation generated by being part of a group in their study that encourages healthy behavior in participants and drives physical activity in positive directions [7]. In addition, it has been proven that regular walking exercise contributes to people's well-being in life [8]. We also confirmed the positive results of the study on the effect of cooperation with walking partners or groups [9]. Futami *et al.* (2021) presented a competition system using the number of steps and confirmed the positive effect of competition factors on motivation to walking [10]. Thus, based on our understanding of the social effects of physical exercise, we considered the increasing motivation for walking exercise through interactions with a 3D avatar as a virtual walking partner.

In our system, if there is no one to walk with in the same space, it is completely possible to walk with the avatar. However, if there is someone who can walk in long-distance remote location, the user can experience the sense of walking together using the avatar at the same time. As a way to share the walking experience with long-distance remote users, various methods for recognizing the user's gait have been studied, there are several studies using auditory feedback [11–13]. Among them, the method using haptic feedback, Baldi *et al.*(2020) presented a method of using a wearable device to share a walking experience with a person located in a remote place [3]. The user can recognize the walking of the remote user through the vibration of the wearable device. Unlike the above studies, our study provides visual feedback through a 3D avatar in Augmented Reality which can provide a more intuitive walking exercise experience. Since we confirmed the effect of being with a group or partner during physical activity through a related study, we applied the two factors of cooperation and competition to the user through the sense of presence in the avatar. And we investigated that the use of the social aspect of physical activity is effective in increasing the motivation of walking exercise.

A related study on the effect of Augmented Reality for walking support, we confirmed that the provision of virtual information can support human walking. Lages *et al.* (2019) investigated properties of adaptation-based interface techniques. It is can be used to guide the novel design of walking experience in Augmented Reality work space [14]. In our study, we tried to increase usability by providing an interface that users can use intuitively without a separate learning process, such as command input through voice recognition, control of avatar movement synchronized with user movement, and direction control of avatar by user's gaze tracking.

2.2 Effectiveness of Walking Partner

Few studies have investigated the effectiveness of walking exercises directly with a virtual partner. We designed a virtual walking partner using a 3D avatar. The 3D avatar was implemented in the form of a full-body human shape. Related studies on the implementation and effect of walking partners are largely divided into physical partner and virtual partner depending on the form. Typically, physical walking partner is using a robot. Karunarathne *et al.* (2019) presented a Humanoid Robot as a walking partner and conducted a study on the effect. The results represented that participants responded higher ratings to the walking with robot partner than walking alone [15]. The effect of the robot as a walking partner was found to alleviate the loneliness of users walking alone or to increase the exercise effect and even medical effect as well [16–18]. We confirmed positive feedback on the effects of walking partners through related studies. In particular, direct effects on exercise effects and motivation support the goal of our study. However, in the case of a robot partner, a complete human form or two-leg walking has not yet been implemented due to technical limitations. It still has many challenges in terms of user experience.

Virtual Reality and Augmented Reality technology is the main idea to realize a virtual partner. In this study, we designed a virtual walking partner using Augmented Reality technology. Norouzi *et al.* (2019) presented walking with a virtual dog implemented in Augmented Reality as a partner and investigated participants' perception and behavior. The findings showed that experience with an Augmented Reality dog as a companion changes participants' behavior and social interaction with other people [19]. Through this study, we confirmed positive feedback on the effectiveness of virtual objects as partners. Above all, these studies support the fact that interactions with virtual objects can also affect the emotional part of users. We believe that the effectiveness of a virtual partner depends on how realistic it is to feel. It is required not only to provide visual information to user but also to convey a sense of being together. There are already many existing devices and applications that support walking exercise. The difference of our study is that a novel interaction is designed based on the fact that there are limitations in motivation only with existing methods. There are still many awkward interactions with the real space that go beyond physical common sense to the human's perception. As a study to overcome these limitations, Kim *et al.* (2021) investigated and designed an effective method for the impact of visual effects that can improve the limitations in the collision situation between Augmented Reality virtual humans and real objects [20]. Several other studies have attempted approaches such as applying visual effects and psychological improvement methods to improve the user recognition effect of Augmented Reality [21, 22]. In our study, we use the spatial awareness function of HMD (Microsoft HoloLens2) to express the behavior of a virtual partner physically in the real space. Common-sense behavior of the virtual avatar can be expected to improve the user's real sense of presence in the avatar. Our system is designed so that the user can interact with the avatar through an intuitive interface, assuming various situations that may occur in the walking exercise scene.

2.3 Interactive 3D Avatar in Augmented Reality

We designed a 3D full-body avatar as a virtual partner. A high level of the real sense of presence can be expected by creating an avatar with appearance and physical conditions that is most similar to a real human. And since it is placed in the real space with Augmented Reality technology, the user can intuitively recognize the avatar as a partner. Few studies have investigated full-body 3D avatars as direct walking partners. But most related studies using avatars are mainly for remote collaboration, and through this, we are able to confirm positive feedback on the effect of cooperative work with virtual avatars. We considered the creation of an avatar in an appropriate shape according to the related research on the shape of the avatar. The effect of 3D model in Augmented reality is studied in the domain of education, and it has been applied to physical education and sports. Chang *et al.* (2020) represented the effectiveness of 3D model in Augmented Reality on physical education. Unlike the video-assisted instruction method, a system provides interactive feedback through an Augmented Reality 3D model to learners [23]. Koulouris *et al.* (2020) investigated the effectiveness of three types of avatar which are generic('Lego figure'), realistic and idealized avatar as a partner in VR exergame system [24]. Praetorius *et al.* (2021), the effect of the shape of the avatar according to the context, according to above studies, we confirmed that the avatar close to the human shape is preferred in the context where an intimate relationship [25]. We found that the shape of the user-friendly avatar as a walking partner is a significant factor in increasing the effectiveness and motivation of walking exercise.

In our system, the remote user's appearance is expressed using an avatar to enhance the remote cooperation effect. In most the related studies, an extra capture sensor was used to capture the user's motion. The method of visually realizing the avatar was displayed directly in front of the user's eyes using an HMD [26–28]. In our system, the appearance of a remote user was designed as an avatar to provide a sense of mutual presence, but we designed a method that does not use an extra sensor to capture the user's movement. In order to maintain a hands-free user experience due to the characteristics of walking exercise, a method for synchronizing the movement of the avatar and the user using the only HMD was designed. Telepresence implemented in Augmented Reality is applied for a realistic simultaneous experience with remote users. Mainly, telepresence was used as a method for remote collaboration. In our study, telepresence was applied by assuming that the simultaneous walking experience with a remote user as a kind of collaboration. In many of existing studies, a method was used to acquire the user's appearance and movement data using a camera and motion capture sensor and display it to a remote user [27, 29]. This method has disadvantages in that user space is limited and costs are high. The usage of our study is outdoors without boundaries. Therefore, the use of complex equipment, bulky device, and sensors is disadvantageous of walking exercise. Thus, a method using only HMD was designed, and telepresence was implemented by synchronizing the movement of the avatar implemented in Augmented Reality with the remote user. In our study, the interactive 3D avatar implemented as a virtual walking partner interacts with the user alone or with the local user by synchronizing the movement of the remote user. In both cases, the real sense of the presence of the avatar is an important factor for increasing the motivation of walking exercise. Thus, since our study used Augmented Reality in real space so that we designed an interactive system that allows users to empathize and collaborate with a virtual walking partner and we investigate its effectiveness as well.

Chapter 3

Research Goal and Approach

3.1 Problems

We found a problem that people often decrease their motivation when they walking exercise alone [3]. We designed an Augmented Reality system to solve the lack of motivation in walking exercise. Existing methods alone have limitations to increase the motivation. In this study, we explored the following specific problems:

- **Absence of walking partner:** Due to the time and space limitations [3], people have no choice but to walking exercise alone. Existing methods do not provide an appropriate form of virtual walking partner such as a full-body human avatar.
- **Limitation of simultaneous walking experience between remote users:** Various methods have been designed to overcome the space limitation[3, 12, 13], but mainly in the way of providing auditory and tactile feedback. We believe it is necessary to provide visual and auditory feedback for an intuitive experience of walking together.
- **Lack of the motivation of walking exercise:** User's experience of walking exercise alone is difficult to maintain or increase the motivation of activity. We believe it is necessary to increase the motivation of walking exercise in order to achieve the ultimate individual's physical and mental health [8] through the walking exercise,

3.2 Goal

We present an interactive full-body 3D personalized avatar in Augmented Reality as a virtual walking partner. Our research goal is to increase the motivation of walking exercise using a 3D avatar. We investigated how interaction with a virtual partner can increase the motivation of walking exercise. The detailed requirements for achieving the goal are:

- **Enhancing the sense of presence in virtual walking partner:** Provision users the realistic sense of the presence of an avatar as a virtual partner is a significant factor of this study. Our system does not simply show digital content, but provides to the user with a sense of interaction with a real partner. Thus, the system design focus on the appearance and behavior of the avatar as a real person.

- **Provision of the sense of mutual presence between remote two users:** In our study, we designed a system for providing an experience of walking together for two users located in a long distance at the same time. The system provides a partner-appearance avatar in which the user's movements are synchronized and real-time voice chat.

- **Realistic interactions with a virtual walking partner:** Augmented Reality is a key technology for realistic interaction between the physical world and digital content [1, 30]. In our system, we designed realistic interactions with avatars in walking scenes. We expect to increase the motivation of walking exercise through the designed interaction.

3.3 Approach

We designed an Augmented Reality system for increasing the motivation of walking exercise. Our research has the following approach:

1. **Hands-free experience in Augmented Reality:** We designed a hands-free Augmented Reality system for immersive walking exercise experience using HMD and some part utilizes the computing of the smartphone.

2. **Interactive virtual partner depending on the case:** We designed a full-body 3D personalized avatar as a virtual walking partner in the appropriate appearance of each case to improve the user experience.

3. **Realistic interaction between user and avatar in walking exercise scene:** We designed the novel interaction between user and avatar in walking scene to increase the motivation of physical exercise.

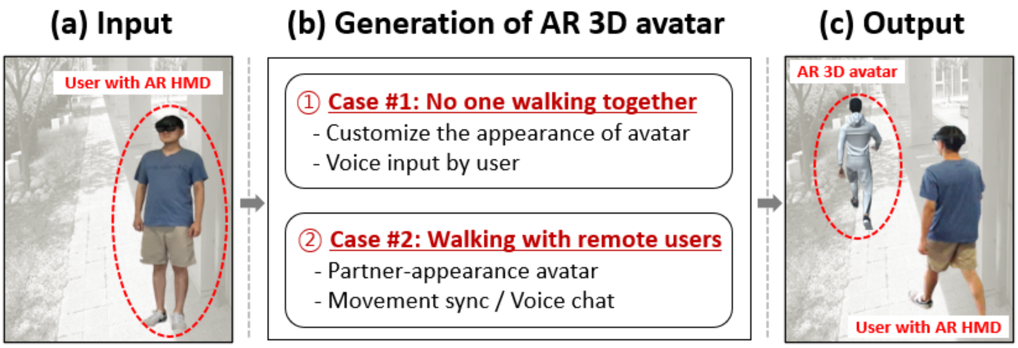


Figure. 3.1 Overview of the system approach

Figure. 3.1 shows the overview of the system approach: **(a)** Input: Real scene through the AR HMD. **(b)** Generation of an AR 3D avatar depending on the case: Each case has different avatar's appearance and the trigger of avatar's action. **(c)** Output: User can walking exercise with an AR 3D avatar as a virtual partner using designed interaction.

We make the following contributions:

- **Novel interactions with a virtual partner in walking scene:** We designed the novel concept, design, and implementation of interactions with 3D personalized avatar in Augmented Reality as a virtual partner to increase the motivation of walking exercise.

- **Novel method of movement synchronization:** We designed the novel method of movement synchronization between user and avatar using the camera position of HMD without extra sensors such as motion capture, record, etc.

Chapter 4

System Design

In our system, we present a full-body 3D personalized avatar as a virtual partner. Augmented Reality technology is applied for realistic interaction with a 3D avatar. We designed a novel system to present interactions that provides a walking experience with a virtual partner. The considerations of the system design are:

- **Interactive 3D personalized avatar as a virtual walking partner:** In our system, users can customize an avatar including appearance and body details. It can be expected to make a better user walking experience [4, 25, 31]. User interfaces of interaction are designed intuitively and understandable, e.g. voice, touch, and movement itself.

- **Realistic interactions with a virtual partner in walking scene:** System supports the realistic interactions among users, an avatar, and the physical world to achieve the goal of this study. We designed novel interactions that provide the real sense of presence to the avatar. Thus, user can experience as if walking together with an avatar as a virtual partner in Augmented Reality.

- **Movement synchronization between the user and avatar:** We designed a novel method of movement synchronization between user and avatar for a simultaneous walking experience using the camera position of HMD, unlike the existing method of motion capture by the various extra sensors [27, 29].

4.1 System Overview

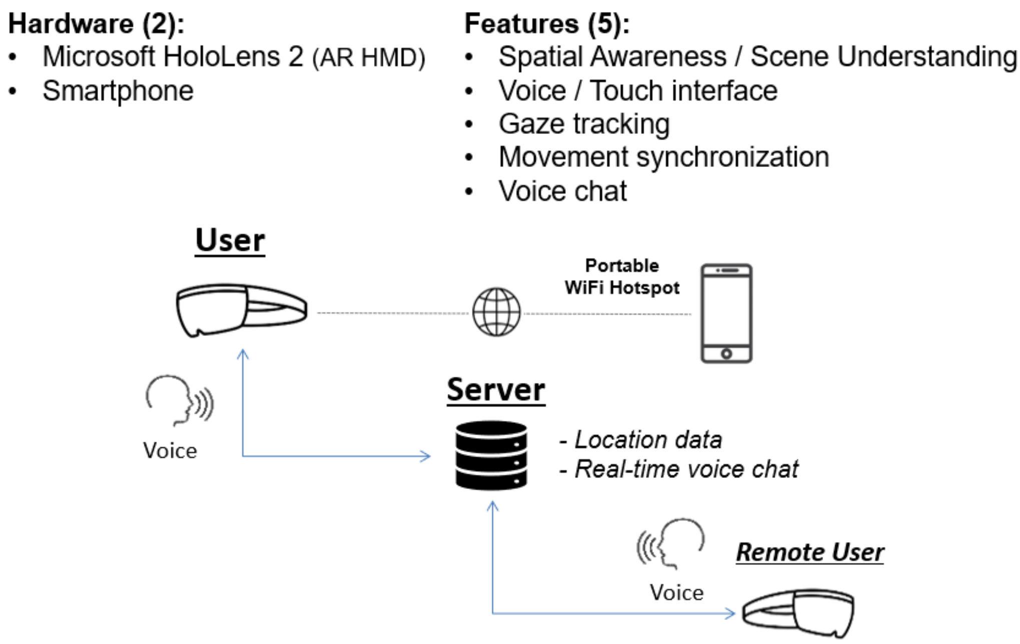


Figure. 4.1 System Overview

Figure. 4.1 shows the overall structure of our system. In system components, Augmented Reality HMD (Microsoft HoloLens 2) and smartphone (Samsung Galaxy S10) are used as hardware devices. HMD is a display device that is mounted on the head. It has the characteristic of providing virtual reality and Augmented Reality easily by combining various sensors and input devices. The HMD allows users to experience a fully immersive virtual environment [32]. In this study, an Augmented Reality system is implemented using an optical see-through HMD to fully utilize the physical space, Microsoft HoloLens 2 that can view the physical world and the display screen at the same time. It can be expected to provide interaction among the physical world, user, and avatar. In addition, we believed that the use of HMD that can provide a hands-free Augmented Reality experience is most appropriate considering the characteristics of walking exercise. Considering the features of the walking exercise, the system consisted of a minimum of hardware to provide a hands-free walking experience. In particular, since the use of smartphones has become common in the recent years of physical activity environment, we also considered utilizing the computing of smartphones as well. We used a server to synchronize the movement of the user and the avatar and real-time voice chat. The connection between the HMD and server is made in the state in which the network connection is established. In the case of Microsoft HoloLens 2, since WiFi is supported, and when connecting to a network, the device itself can use the Internet environment. Therefore, in this study, we used a server that can be implemented through the device's internet connection. Interaction between local and remote users use each HMD. Each HMD connects to the network through its computing. It supports sending and receiving data between two users through the server under the network connection. In this system, we designed a simultaneous walking experience between remote users by using a method that synchronizes the movement of the avatar with the user. Using the multiplayer game idea, we used a method similar to that of two players connected to the same room to control the corresponding character. We designed a synchronization method using HMD without using a separate sensor, device, or equipment.

As a further features, we used built-in features of Microsoft HoloLens 2 [33], e.g. spatial awareness, scene understanding, voice / touch interface, gaze tracking. Our system can be provided not only the visual but also auditory feedback. In our system, the smartphone was used as a portable WiFi hotspot to provide an outdoor internet access environment. The use of the system is divided into the case of one user and two users. Specific use cases are covered in the next section. The cases depending on the number of the user are:

- **Single user case:** User wear HoloLens 2 and place one's 3D personalized avatar in the physical space. The system provides an interface, e.g. voice input, eye tracking, touch. And user starts a walking exercise at the desired time and place with the suggested interactions.

- **Two users case:** Local and remote users wear HoloLens 2. The user's movement is recognized using the camera position of the HoloLens 2. The camera position change is determined by the user's movement and the corresponding data is transmitted to the server. Meanwhile, real-time location and voice chat data is transmitted and received through the server.

4.2 Use Cases

Our system has two use cases: *(1)Case #1*: User does not have a real walking partner in the same location at the same time, *(2)Case #2*: User has a partner who can walk together at the same time, but a partner is located in long-distance remote location. Both cases have a corresponding 3D personalized avatar in Augmented Reality. At this point, we believe that Augmented Reality technology is the key idea that can connect digital information and reality most realistically. We designed the interaction to provide an experience that the avatar which is digital information in front of the user's eyes, is not just seen but also a walking exercise together. (see **Figure. 4.2**)

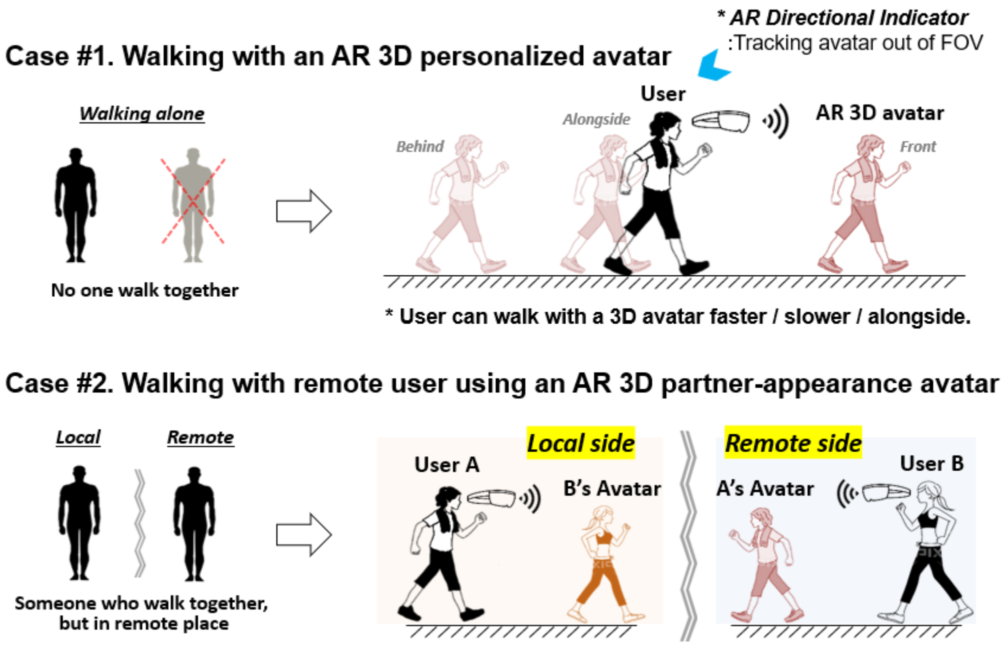


Figure. 4.2 Two use cases of system

In this study, the user can select the interaction depending on the user's preference in consideration of their own situation. In both cases, it is used in the absence of a physical walking partner in the same space. We believe that the effectiveness of a virtual walking partner will be determined by how much it can replace the role of a physical partner. Thus, we analyzed two possible cases in advance for the design of interaction and focused on implementing a 3D avatar that displays feedback appropriate to the situation.

4.2.1 Case #1. Walking with AR 3D Personalized Avatar

In this case, a user performs a walking exercise with a virtual partner when a physical walking partner does not exist. The form of the virtual partner is provided as a full-body 3D personalized avatar. Augmented Reality technology is applied for the implementation of realistic interaction with a virtual partner. The system provides a user with a real sense of presence by implementing a virtual partner in the form of a human. We believe that the motivation of walking exercise will be increased because the user conducts a realistic interaction with the virtual partner in the walking exercise scene.

Users can customize the appearance of avatars, e.g. oneself or acquaintance. A user-friendly avatar can be provided a better user experience. And then, user can interact with 3D personalized avatar in Augmented Reality while walking together. Case #1 is divided into three types of walking interactions depending on user's preference: *(1) Normal*: In any course, user can walking exercise normally with an AR 3D avatar, *(2) Pacemaker*: In the routine course, user can comparative walking with AR 3D avatar who has user's previous walking record, *(3) Competition*: In the certain distance, user can compete with AR 3D avatar with simple rule e.g. first comer wins the competition.

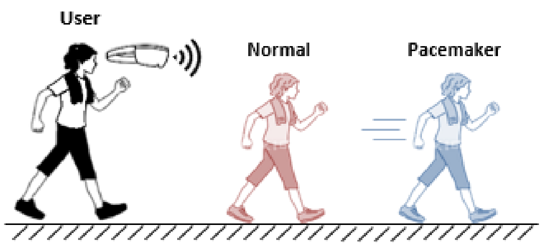


Figure. 4.3 Walking with AR 3D avatar

The suggested walking exercise type is designed assuming a situation that can occur frequently during walking exercise. In this system, the user can select a walking type according to the user's preferences and purpose. We designed appropriate behaviors and interactions for each type with an AR 3D avatar which our virtual walking partner. In common, all of three types are implemented for the purpose of enhancing the user's motivation for walking. Augmented Reality technology supports user to feel the digital content avatar as if a real partner. In addition, we designed intuitive interfaces for user's immersive walking exercise experience with a virtual walking partner. User can interact with an AR 3D avatar using voice input, user's gaze, and movement.

4.2.2 Case #2. Walking with Remote User using AR 3D Avatar

If a real walking partner exists in a remote location, it is difficult to share the sense of walking together experience at the same time. In previous studies on the simultaneous walking experience between remote users, a method using auditory and tactile feedback was presented [3, 12]. However, we designed a method that enables visual feedback by applying Augmented Reality technology. In our system, walking together experience between local and remote user is provided using 3D partner-appearance avatar. AR 3D avatar which has partner-appearance is displayed in front of each user's vision. The movement of the avatar is synchronized by remote user's location data using the camera position of HMD, and real-time voice chat can be provided between two users. (see **Figure. 4.4**)

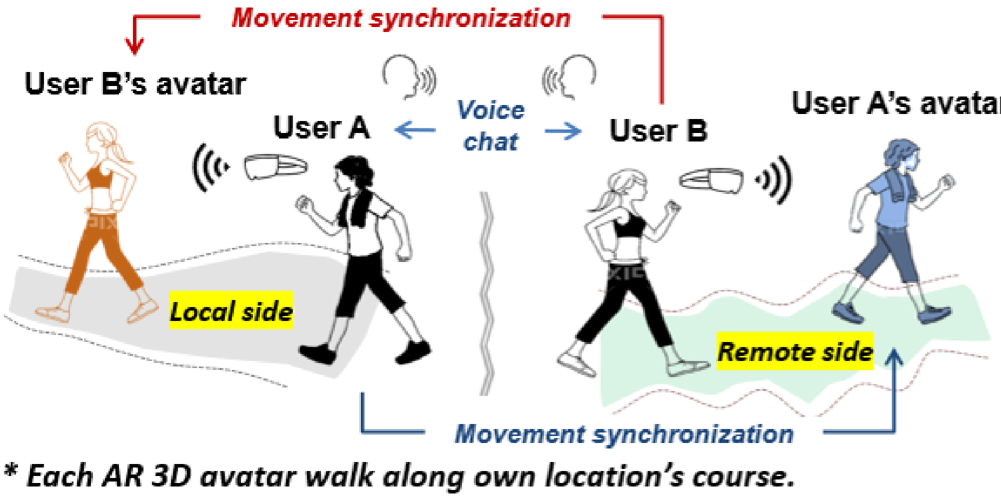


Figure. 4.4 Movement Synchronization between User and Avatar

We designed a method to synchronize the movement of a remote user with the movement of an avatar located in front of the local user's field of view. That is, the local user experiences the walking exercise while watching the avatar moving according to the movement of the remote user in front of one's eyes. We expect that the movement of remote user is visually provided through 3D avatar as a virtual walking partner, and it will provide the sense of mutual presence most intuitively. In addition, we enhanced the mutual presence between the two remote users through real-time voice chat in our system. Through this system, the user recognizes the movement of the user who is not located in the same space through the

3D partner-appearance avatar and performs with a walking exercise while having a natural conversation at the same time. Thus, we expect this interaction to increase the two user's motivation for walking exercise.

We designed interactions that movement synchronization and real-time voice chat to provide the sense of mutual presence [6, 26, 28] to the user. It makes user can perceive the sense of the presence of remote user even two users in a separate location. As a consideration, avatar only can walk along the course of own location's course regardless of the different course shape on both sides. It resolves the issue that different shape of course. In addition, different partner's statuses or levels of walking issues depending on different gender and age are resolved by changing the walking speed of avatar. According to the related work [34], the general walking speed of depending on gender and age respectively. In our system, we can apply for avatar's different walking speeds as a default setting. Since the local user can experience different walking speeds according to the condition of the remote partner, it can be possible for each user can walk while realizing the unique characteristics of the partner.

4.3 Interactive Full-body 3D Avatar as a Virtual Partner

In psychology, *'Köhler effect'* [35] known as a phenomenon that occurs when a person works harder as a member of a group than when working alone. In addition, many research on physical exercise has been found that exercising with a partner or group improves effectiveness and motivation of exercise [3, 5, 36]. In our system, we used 3D personalized avatar as a virtual partner of the walking exercise. Thus, the user can perform a walking exercise while having a realistic interaction with a virtual partner implemented in Augmented Reality. Especially, social aspects of interaction with a partner, i.e. cooperation, competition, and encouraging, are expected to increase the motivation of walking exercise. An avatar used in our system can be recognized by user as a virtual partner. Designed full-body 3D personalized avatar in Augmented Reality can be provided the sense of real walking together with partner to the user, e.g. avatar action can be changed by user's voice input, and can be represented reaction by interaction with a physical object. The interfaces for realistic interaction between user and avatar are:

- **Voice input:** Voice is the most intuitive interface to input a user's command to the avatar. In our system, voice input used as a command for avatar action change, e.g. walking start / stop, sitting on the bench, etc. were used.
- **Touch interface:** In our system, touch interface is applied for high-five interaction between user and avatar for encouraging.
- **Gaze tracking:** In order to control the direction of the avatar, a method of tracking the user's gaze is applied when the avatar changes direction. In our system, the direction of the user's gaze can be a controller itself, because the user wears the Microsoft HoloLens 2 which is a see-through HMD.
- **Object detection:** System can recognize a physical object by object detection on image processing. After recognition success, a corresponding action can be performed according to the result of the object detection, e.g. sitting on the physical bench, etc.
- **Recognition of the distance between the user and avatar:** System recognize distance between the user and the avatar. The corresponding avatar action for encouraging to the user can be represented according to the distance, i.e. how the avatar far from the user.
- **Perception of physical object:** System recognize the physical world by Spatial awareness feature of HoloLens 2. In our system, avatar can collide with physical object, e.g. wall, barriers, etc. After the collision occurs, an avatar can be represented visual and auditory feedback to the user.

Our study can be expected to increase the motivation of walking exercise because the designed AR 3D avatar provides an experience of walking together with the user using realistic behavior such as real human rather than simply observing and watching digital content. We believe that because the experience of walking exercise with a virtual partner can be provided, users will overcome the limitations of physical time and space issues.

4.3.1 User-friendly Appearance of Avatar

To achieve the goal of this study, the provision of realistic virtual partners is a significant factor. Our system provides a full-body 3D avatar. This is because the user can most intuitively recognize the existence of the virtual partner. User can be customized the appearance of the avatar by oneself or an acquaintance, e.g. friends, family members, etc. When interacting with the avatar, it can be improved the user experience and intimacy between user and avatar. In case #1, the user can customize the appearance of the avatar. In case #2, the avatar is created with the appearance of a remote user to enhance the sense of mutual presence between two users.

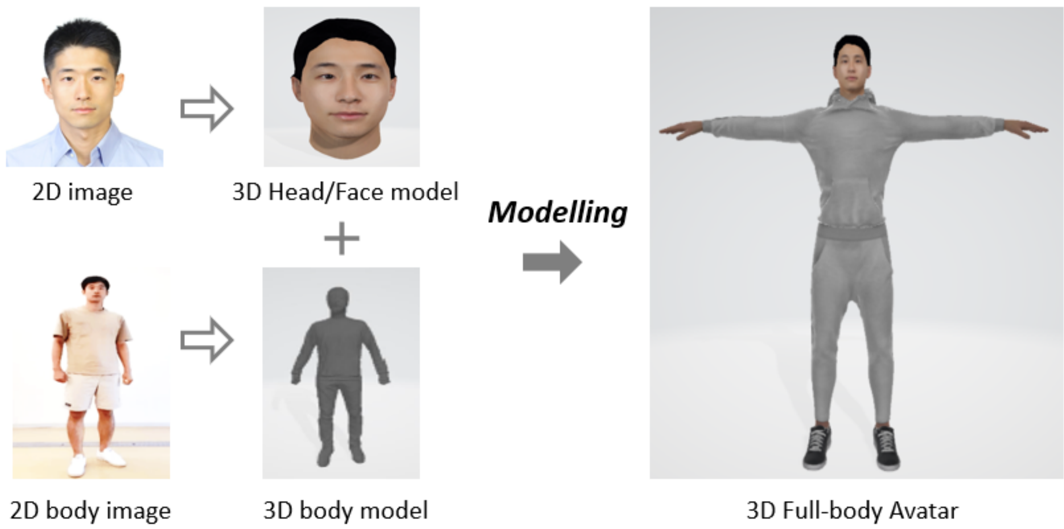


Figure. 4.5 Concept of customization in full-body 3D avatar

Figure. 4.5 shows how to design a user-friendly avatar. In our system, an avatar is created using a 2D image of the face and body. First, a desired face and body image is captured by the user *(In our system, we used an off-the-shelf smartphone camera)*. Using these images, a 3D model of the head/face and body is created. Finally, the generated 3D models are combined to create a 3D full-body avatar with the desired appearance. This process is a result generated from a 2D image taken with a commercial smartphone and a free software development kit(SDKs). It supports the user to create easily an avatar without time-consuming.

4.3.2 Design of Avatar Actions in Walking Exercise Scene

The target of this study is a walking exercise, thus, the avatar actions are designed that may occur in a walking scene. It starts from ready to walk action, e.g. breathing and quick stretching as a warming up. And then, it has started and stopping walking action, walking along a course. In addition, it reacts if colliding with a physical object, sitting on a bench for taking a rest. If necessary, it has encouraging actions to the user, e.g. clapping, high-five with avatar. In order to enhance the realistic interaction with the virtual walking partner avatar and the user's sense of immersion, it is designed with a focus on the most frequent actions in the actual walking exercise scene.

<table>
<tr><th>AR 3D avatar action control</th><th>Interactions</th><th>Routine course</th><th>Any course</th></tr>
<tr><td rowspan="2">• Voice input
• Remote user's location data</td><td rowspan="2">• Walk along the road
• Sit down
• Encouraging
• Collision / Reaction</td><td colspan="2">• Walk along the walking course
• Competition walking</td></tr>
<tr><td>• Comparative walking</td><td>-</td></tr>
</table>

Figure. 4.6 Design of interactions with AR 3D avatar

Figure. 4.6 shows the design of interactions in our system. The avatar actions are designed to be realistic according to interactions. In addition, some interactions were applied depending on the walking course, e.g. in the case of the routine course, a comparative walk is provided that the user can walk with an AR 3D avatar who has the user's previous walking record was applied. In competition with user, the designed AR 3D avatar can be represented simple emotions through the actions according to the context of the user and situation, e.g. if the avatar wins, the avatar can express enjoyment using victory action, and if the user wins, the avatar can express disappointment using depressing action. In addition, the system recognizes the distance between the user and avatar during the walking exercise, and when a specific distance occurs, the system recognizes that the user is tired, which means the user cannot follow the avatar, and then the avatar performs an action to encourage the user, e.g. clapping, high-five.

4.4 Social Aspects of Interactions in Walking Scene

One of the most obvious benefits is having others pushing the user to do one's best. Usually, we can call it the terms of motivation [37]. When we have performing physical exercise, usually difficulties such as lack of motivation has occurred. It can be overcome by exploiting its social aspects [3]. However, our current lifestyle usually makes it very hard to find physical partners in desired time and place. Designed interactions in this study, considering social aspects of walking exercise, are expected to make user increase their motivation. In our system, the user and the avatar cooperate or compete to improve the user experience and increase the motivation of walking exercise. Cooperation and competition in each case are:

- **In case #1:** User can perceive one's avatar as a virtual partner. It can be considered the target of cooperating and competing together.
- **In case #2:** The sense of the presence of the remote user is provided through the avatar. Interactions between user and avatar using an avatar can be regarded as an experience between two real users.

4.4.1 Cooperation

Cooperative exercise was found to increase motivation, continued exercise, positive self-esteem, even social behaviors with others [7]. 3D personalized avatar implemented with Augmented Reality can be provided users with the perception that they are doing a specific action, not just showing the role of digital content only providing information. Through cooperation with the AR 3D avatar, i.e. the recognition of walking together, a partner effect can be expected during physical activity. The important thing in this factor is to recognize that the user is doing a walking exercise with the avatar. The experience of being with someone can arouse interest in users and increase their motivation. The core idea is to make the user aware that the partners are walking together. For this idea, various cooperative interactions is designed in our system. (see **Figure. 4.7**)

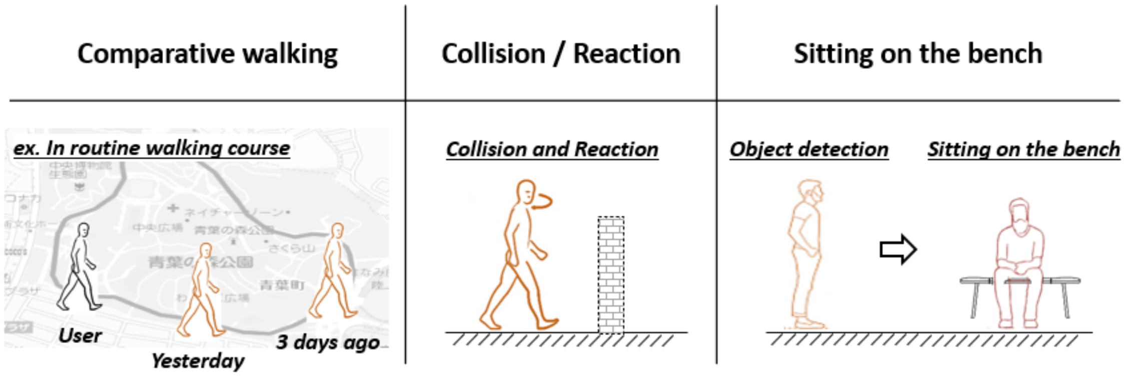


Figure. 4.7 Design of cooperative interactions with AR 3D avatar

Cooperation is a key concept of our system. We designed the system mainly considering the high probability of occurrence. Since real-time response considering context and situation is limited in this system, interaction must be configured by designating predictable situations in advance. This study is also to investigate what kind of cooperation between user as a real human and digital content in a virtual avatar could enhance the user's motivation.

4.4.2 Competition

Competition is one of the effective ways to achieve goals in many domains. The application of competition is diverse. it is mainly used in fields such as sports. It is commonly known that competition has the effect of maximizing human abilities [9]. Although the scope and form of competition is diverse, but the competition of our system are designed to be a continuation of the walking exercise as part of the interaction between user and avatar. In our system, the competition is presented an intuitive goal and can be performed based on simple rules. It can be expected to increase the motivation of walking exercise while competing with the avatar. In addition, in order to enhance

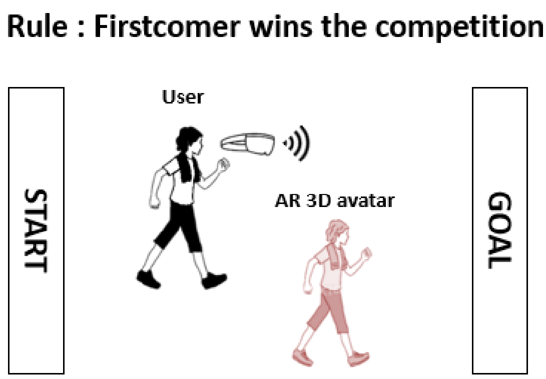


Figure. 4.8 Concept of competition

the sense of realistic competition with the avatar to the user, the emotional expression of the avatar was designed according to the competition result. (see **Figure. 4.8**)

4.4.3 Encouraging

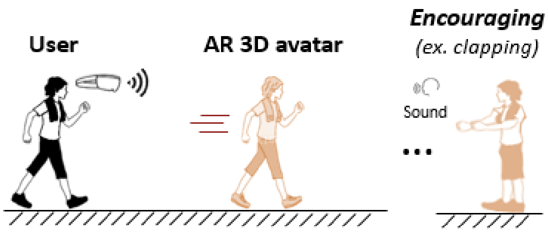


Figure. 4.9 Clapping for encouraging

Encouragement is one of the effective ways to sustain human activity. This is a fact known through various studies and experiences [38]. In this study, an investigation was conducted on the increasing of the motivation for walking exercise through user encouragement. The suggested encouraging interaction is user encouragement by the avatar. To determine the timing of encouragement, the system is based on the distance between the user and the avatar and the duration of the system of use: ***(1) Distance between user and avatar***: When a certain distance between user and avatar, the system determines that the walking speed is lowered due to the user's fatigue. ***(2) Duration of the system of use***: If more than a certain amount of time has passed, the system determines that the user's fatigue has accumulated.

We provided interactions that avatar's clapping, and high-five with avatar for encouraging in this system. We used the distance between the user and the avatar and the duration of walking exercise as conditions to understand the user's context and situation. This is because it is the most intuitive factor that can predict user's fatigue. Although limitations of current state, this system predicts the user's state based on the above two factors and provides corresponding encouragement action to induce a change in the user's mind through the action of the avatar according to the situation.

Chapter 5

System Implementation

In this chapter, we describe the technical details of solutions and the specific method of implementing the system. We designed an Augmented Reality system using 3D personalized avatar to provide immersive interaction with a virtual partner to the user in walking exercise scene. The implementation has the following three points:

1. **Authoring of full-body 3D personalized avatar:** Full-body 3D avatar is a significant factor to achieve the goal of this research. We designed a simple and quick method using off-the-shelf devices such as smartphone and freeware Software Development Kits (SDK) to create an avatar with the desired appearance without time-consuming.

2. **Movement synchronization between user and avatar:** It is a key idea to provide a realistic mutual presence between two users, i.e. local and remote users feel like both are in the same place. In our system, we designed a method of movement synchronization using the camera position of HoloLens 2 without using separate sensors or equipment.

3. **Realistic interaction that can be occurred in the walking exercise scene:** For an immersive walking exercise experience with a AR 3D avatar as a virtual partner, we designed interaction with an avatar implemented in Augmented Reality through a various interfaces that users can intuitively understand. We designed interactions for appropriate avatar behavior in context and situation.

5.1 Information of System Hardware

We implemented our Augmented Reality system using Microsoft HoloLens 2 which provided spatial awareness capability and optical see-through display. (see **Figure. 5.1**)

Figure. 5.1 Microsoft HoloLens 2 and actual use of device

Among the many features of HoloLens 2, our system starts with spatial awareness which provides physical world awareness when we use the Augmented Reality applications. User can place one's avatar in the physical space perceived by the HoloLens 2. And then, the user performs a walking exercise with the placed AR 3D avatar. (see **Figure. 5.2**)

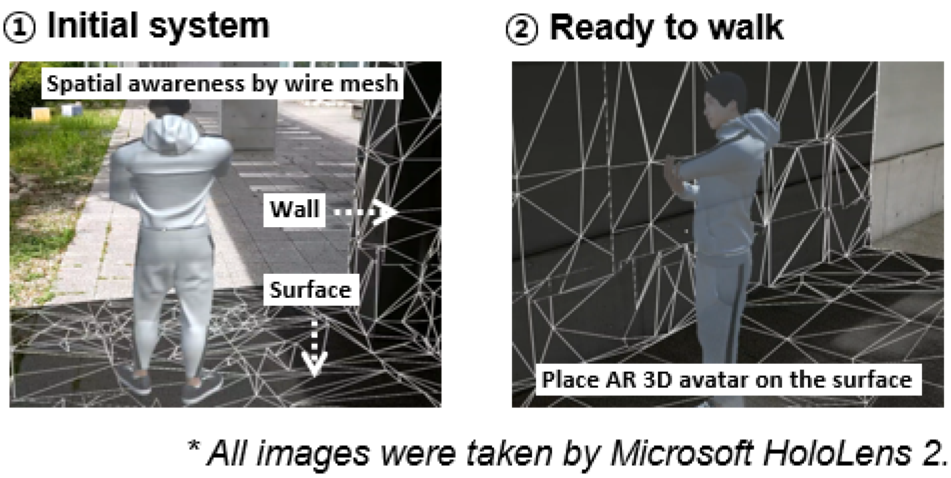


Figure. 5.2 Spatial awareness in our system

5.2 Development Environment

The configurations of the main development computer we used is shown in the below Table. (see **table5.1**)

Operation System	Microsoft Windows 10
CPU	Intel® Core™ i7-8550U Intel(R) @1.80GHz 1.99GHz
Graphics Card	Intel® UHD Graphics 620
Ram	16 GB

Table 5.1 Information of development PC

Since a powerful GPU is required to create the desired animation of avatar in our system, the following PC is used to generation of animation data. (see **table5.2**)

Operation System	Microsoft Windows 10
CPU	Intel® Core™ i9-9900KF Intel(R) @3.60GHz 3.60GHz
Graphics Card	NVIDIA GeForce RTX 2080Ti
Ram	32 GB

Table 5.2 Information of Generating animation data PC

5.2.1 Software

We developed our Augmented Reality system using the following software:

- **Unity version of 2019.4.23f** [39]: It is a cross-platform game engine developed by Unity Technologies, used C# as a programming language. In our system, digital content, i.e. 3D personalized avatar is directly created, and specific movements are implemented using animation data using an animation controller. We designed, developed, and test all of the step before implementing HoloLens 2 in Unity. PUN and Voice for PUN are imported from Unity Asset Store.

- **Blender version of 2.91.2** [40]: It is a open source 3D computer graphics software. In our system. we used Blender to combine face and body model to generate the 3D full-body human model. And it is used for texture mapping of the avatar's body.

- **VIBE(Video Inference for Body Pose and Shape Estimation)** [41, 42]: In order to obtain the desired animation data, we used the video pose and shape estimation method. It predicts the parameters of SMPL which stands for A Skinned Multi-Person Linear Model, body model for each frame of an input video. In our system, we directly took 2D video *(We used the off-the-shelf smartphone)* and used VIBE to extract desired animation data from the video.

5.2.2 Technical Supports

The followings are the technical supports of our system:

- **Mixed Reality Toolkit(MRTK)-Unity 2.5.4** [43]: Microsoft provides a set of components and features, used to Augmented / Mixed Reality application development in Unity. We refer to the component configuration in Demo Scene provided by MRTK. It supports the development of functions that can be implemented in HoloLens 2 as components of Unity when developing an augmented reality system. In our system, the user's voice input, the user's eye tracking of the avatar, the touch interface during high-five action, and the avatar tracking function when positioned outside the user's Field of View (FOV) are supported through the components.

- **Vuforia Augmented Reality SDK 10.1.4** [44]: Cross-platform Augmented Reality and Mixed Reality application development platform, with robust tracking and performance on a variety of hardware. In our system, the **Vuforia Area Target** is used. It enables the user to track and augment areas and spaces by tracking the physical space features [45]. 3D scan of routine course using Light Detection and Ranging (LiDAR) sensor. Using the scanned space, an AR 3D avatar that has the user's previous walking record is created and Comparative walking is implemented.

- **Photon Unity Network(PUN)** [46]: It is a Unity package for multiplayer games. Flexible matchmaking gets users' players into rooms where objects can be matched under the network. In our system, it was used to build a server to synchronize the movement of local / remote users and avatars in case #2.
- **Voice for PUN2** [47]: Photon Voice allows to attach an audio source to a digital object in Unity. It can be attached easily the audio streams. In our system, it was used to implement real-time voice chat between local / remote users in case #2. It is one of the interactions that can enhance the sense of mutual presence.
- **Avatar SDK** [48]: Avatar authoring solution using A.I. technology. In our system, it was used to create a face model of a 3D avatar. A 3D face model can be easily created from a 2D image taken with the off-the-shelf smartphone.
- **BIOHUMAN** [49]: Realistic 3D human body shape maker by physical data developed by University of Michigan transportation research institute. In our system, it was used to create a 3D full-body model by user's input physical information.
- **Mixamo** [50]: Web-based services for 3D character animation. It uses machine learning methods to automate the steps of the character animation process, including 3D modeling to rigging and 3D animation. In our system, it was used for the rigging of full-body 3D model, and also used to acquire some animation data of the avatar.
- **Microsoft Azure Custom Vision** [51]: Custom Vision, included with Azure Cognitive Services, makes it easy to customize modern computer vision models for each use case. In addition, computer vision image analysis using A.I. machine learning is conducted. In our system, the bench image located on the walking exercise course is learned so that the corresponding action, e.g. sitting on the bench, of the avatar occurs when the system identifies the physical object.

5.3 Authoring of Full-body 3D Personalized Avatar

We designed a specific method to create a full-body 3D avatar with the desired appearance by the user. The designed method is to use 2D images of the face and the human body. In addition, the SDKs that we used can be minimized the cost and time consuming by using the web-based solutions and freeware.

5.3.1 Face / head Model

3D face / head model is created using Avatar SDK. Entire steps of generation are possible on the web. It starts from upload a 2D image. Then, Avatar SDK automatically creates a 3D face / head model with completing texture and mapping. The output file format is *.obj for 3D model and *.png for texture. (see **table5.3**)

Figure. 5.3 Generation of face model by Avatar SDK

5.3.2 Body Model

Full-body 3D model is created using BIOHUMAN. It is a solution that can create a full-body 3D model by inputting physical body information to the web. All 3D models generated by BIOHUMAN are based on statistical analyses of a wide range of gender, age of body information, and the results of robust body scan data. Finally, we can obtain *.obj as an output file. (see **table5.4**)

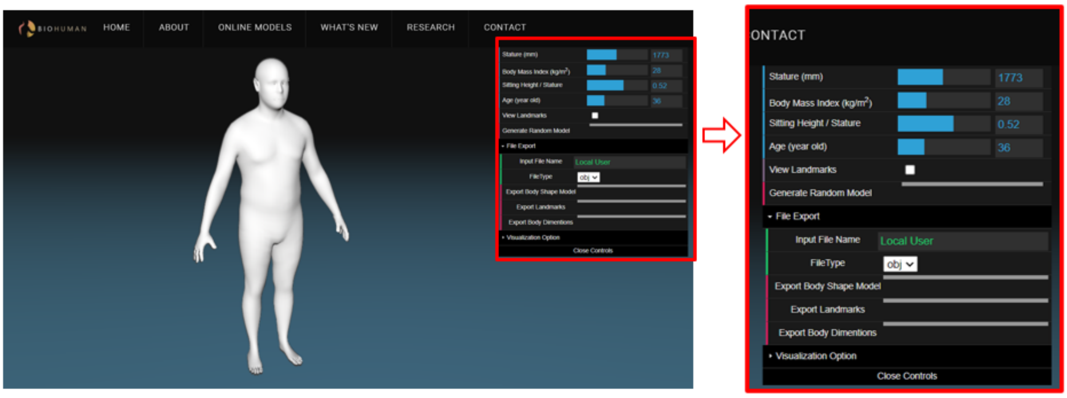


Figure. 5.4 Generation of body model by physical information

5.3.3 Combination with Face and Body model

3D computer graphics software Blender was used to combine the 3D face model and body model. The process of combination is as follows: ***(1)*** Input 3D face and body model on the Blender. ***(2)*** On the scene collection menu, adjust the hierarchy of meshes. ***(3)*** Select body and face meshes together, and then execute joining mesh and texture mapping. ***(4)*** After combining, the created full-body 3D avatar is saved including the texture mapping file. ***(5)*** Finally, completed 3D personalized avatar can be extracted in *.obj (or others also supported) format. (see **table5.5**)

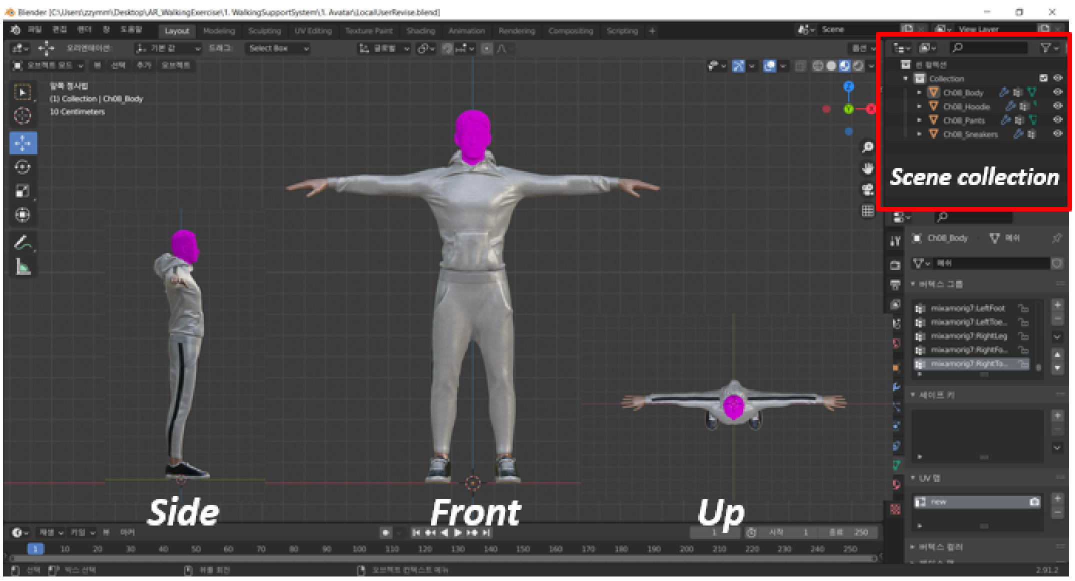


Figure. 5.5 Combination with face and body model in Blender view

5.3.4 Rigging of Avatar

To make the created full-body 3D avatar move, i.e. to apply an animation to the avatar, a rigging task is required. It is the task of creating a bone structure to the avatar. For this task, we used the web-based Mixamo solution. In our system, it makes a realize the idea that avatar has natural behaviors, e.g. do stretching as a warming up, walking smoothly.

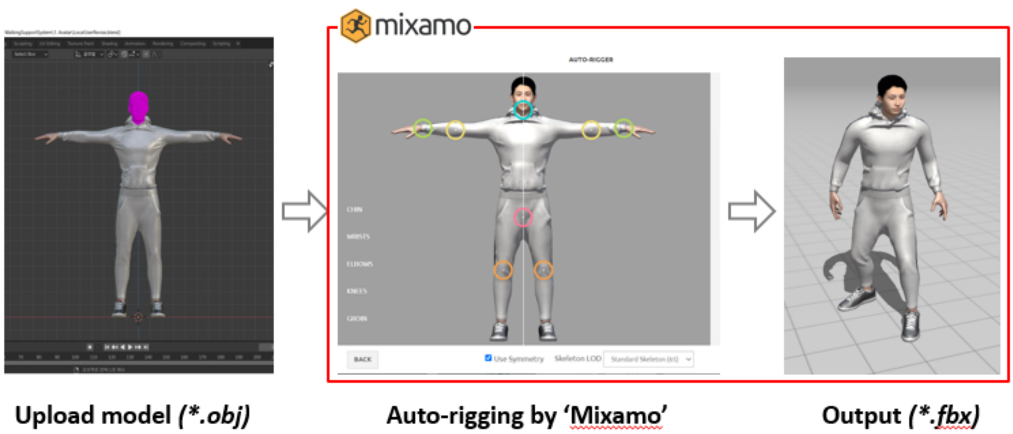


Figure. 5.6 Rigging of full-body model

Figure. 5.6 shows the task of rigging, ***(1)*** Compress the texture file *.png together with the *.obj file of the full-body 3D avatar. Then, ***(2)*** Upload the compressed file *.zip to Mixamo. ***(3)*** After uploading, it need to place markers on parts of model which are chin, wrists, elbows, knees and groin for auto-rigging. And then, ***(4)*** Mixamo generate rigged full-body 3D avatar automatically, the output file format is *.fbx.

5.4 Generation of Avatar Animation

We used animation data to implement natural avatar movement. In our system, the desired animation data for the avatar's action is obtained and generated through two methods. ***(1)*** First, we used the download animation data provided by Mixamo. ***(2)*** Second, we used VIBE solution to obtain by directly producing the desired animation data from the 2D video. We used the animation data obtained from both methods to compose the desired behavior in Unity. The details of each method are as follow:

1. **Download from Mixamo:** We can use animation data provided by Mixamo. We can download avatars that have animation data, e.g. walking, idling, stretching, etc. We can extract only animation data in Unity. It can be applied to our 3D personalized avatar to be used in the system. We can assign, edit and use the desired part of the animation data downloaded from Mixamo. As a virtual walking partner, we can edit in Unity so that natural movement can be achieved.

2. **Generation by VIBE:** The source code of VIBE can be downloaded through the corresponding *github* page [41]. Refer to Tutorial and perform installation and ready to work. We can create an animated 3D model directly through 2D video input. As a procedure, we took a 2D video with the off-the-shelf smartphone *(We used Samsung Galaxy S10)*. For this task, powerful GPU performance is required. VIBE makes an animated 3D model after capturing human motion from the 2D video, and makes output as a file format of *.fbx, is created. (see **Figure. 5.7**)

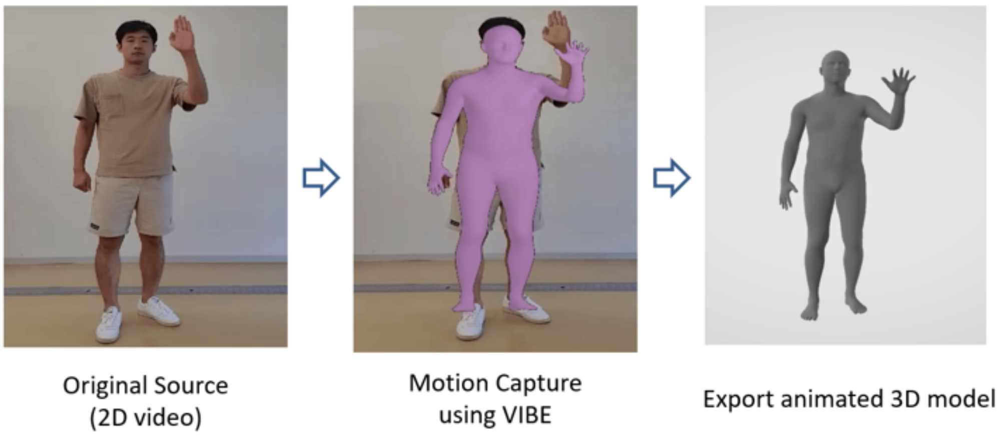


Figure. 5.7 Process of VIBE solution

In our system, the animation construction of the avatar is a part to increase the sense of the reality of a virtual partner. Animation is constructed based on predictions of various situations and conditions that may occur in the walking exercise scene. Animation construction is applied to the avatar through the animator component supported by Unity. Specific animation setting is designed in detail through the animation controller. The followings are the steps to apply animation data to the avatar imported into Unity: ***(1)*** Set the animation type to Humanoid. ***(2)*** Create an animation controller. ***(3)*** All the animations of the avatar are subdivided and composed, e.g. in order to implement a natural walking action, start, walking, and stop actions are configured. ***(4)*** Process between each state is controlled by specifying parameters by C# scripts. (see **Figure. 5.8**)

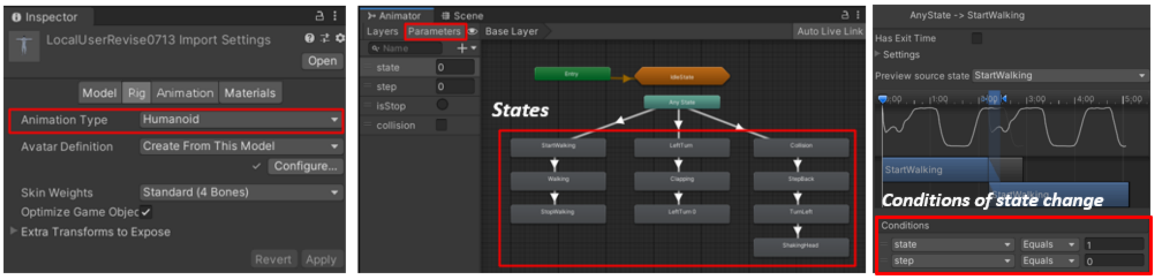


Figure. 5.8 Configurations of animation controller

5.5 Interactions in Walking Exercise Scene

5.5.1 Action Change by Voice Input

The system has voice input to control the actions of the avatar, e.g. the avatar's walking action is initiated by the user's voice command. Voice input feature is provided MRTK toolkit, *Input - Speech Commands*, specifies the voice command to be used. And, through the *Speech Input Handler* component, the animation data corresponding to the specific voice command is designated as a C# script. (see **Figure. 5.9**)

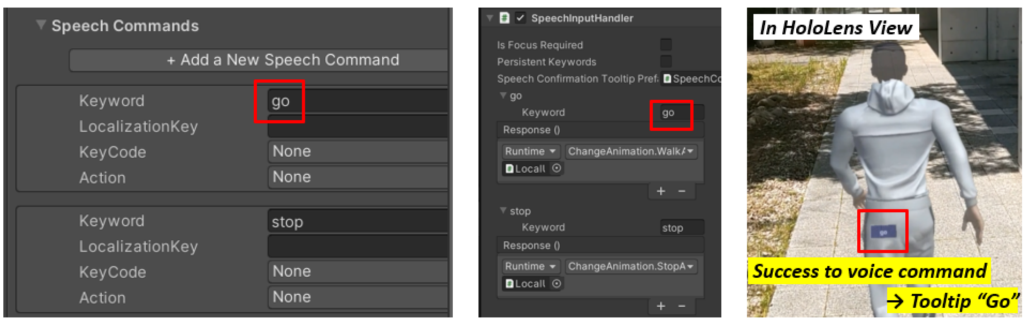


Figure. 5.9 Application of voice input

5.5.2 Movement Synchronization between user and avatar

We designed a novel method of movement synchronization between the user and the avatar. This method is implemented using the camera position of the AR HMD (Microsoft HoloLens 2) without using separate sensors or equipment. Thus, two users can feel the mutual presence by synchronizing the movement of the remote user with the movement of the avatar which in front of the local user's vision, while providing the user's hands-free experience. The user's movement state is classified as idling / walking. The user's movement is determined by the camera position, i.e. coordinate value of HoloLens 2.

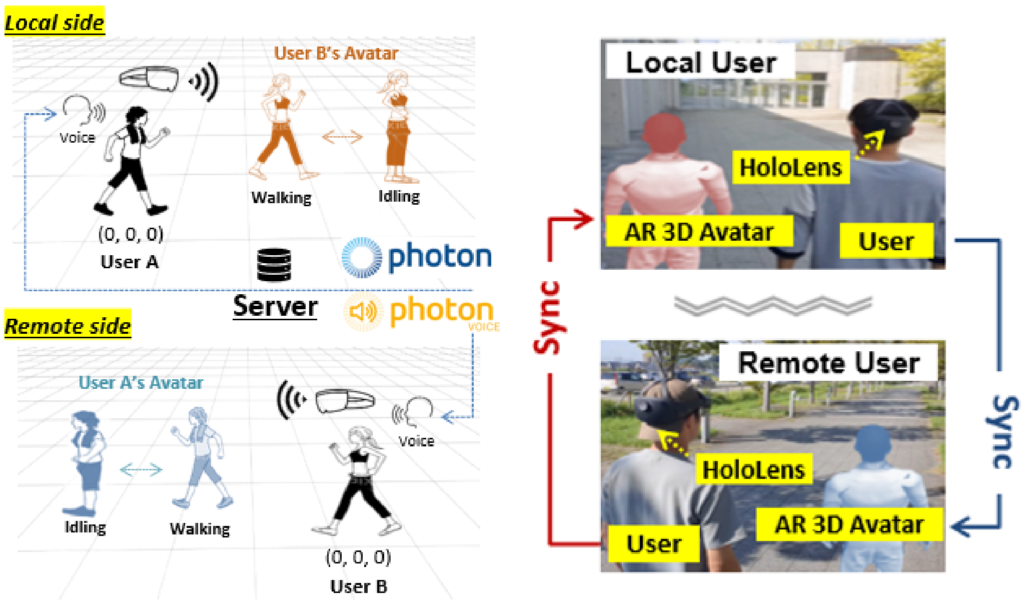


Figure. 5.10 Method of movement synchronization

Our system recognizes the change of 'z' value as the coordinate system of HoloLens 2 as a change in the user's position. And it changes the action of the avatar according to the user's position change. The current location of the avatar is created as an initialized location when the system is initialized. The position of the HoloLens 2 camera, i.e. the user's position, has a coordinate value of (0, 0, 0) when the system is initialized. Based on this coordinate value, the position of the avatar is set to (0, 0, 1) by changing only the 'z' value so that it can visible the user's gaze. For reference, the camera coordinate 1 value of HoloLens 2 means 1m in physical space [52]. When the 'z' value of the remote user is changed based on the above coordinates, the system determines that the user's walking exercise has started. The movement of the avatar is controlled by changing the coordinates of the remote user according to the movement synchronization. In order to determine the movement of the user, it is necessary to initialize the current position to the previous position every time. Thus, in the code level, when the value of the current position is greater than the previous position, an algorithm (see ***Algorithm 1***) for determining that the user is moving. Specifically, a C# code is implemented to initialize the current position with the previous position in every frame. Aforementioned, if the current position is greater than the previous position, the action state of the avatar is moved to start walking by changing the parameters of the animation controller. Otherwise, the state is changed to stop walking.

Algorithm 1 Avatar action change depending on HMD camera position

Require: Initialization of previous position as a current position

$Y \leftarrow PreviousPosition$
$X \leftarrow CurrentPosition$
if $X > Y$ **then**
    $SetParameter \leftarrow$ **START***walking* ▷ *Changing animation state*
    $PreviousPosition \leftarrow CurrentPosition$ ▷ *Update by z value in every single frame*
else
    $SetParameter \leftarrow$ **STOP***walking*
end if

The concept of the multi player game is applied to represent avatars with synchronized movement. First, local / remote users can access the same Room. The basic structure of server construction is as follows: *(1)* Create network account, *(2)* Connect network and callbacks, *(3)* Matchmaking: Lobby / Room, *(4)* Player synchronization. (see **Figure. 5.11**) For implementation, build local / remote user applications separately. Each application is applied to the opponent's avatar in the player prefab. After initializing the application, both users connect to the same room, but each user can only see the other's avatar. The avatar's movement is synchronized according to the location data of the corresponding user's HoloLens 2 camera. Since the movement of the HMD coincides with the movement of the user, HoloLens 2 itself is used as a controller to control the movement of the avatar. In this study, only the case of two users is considered. However, we expect to be able to consider the participation of more than one user depending on the capabilities of the server. (see **Figure. 5.11**)

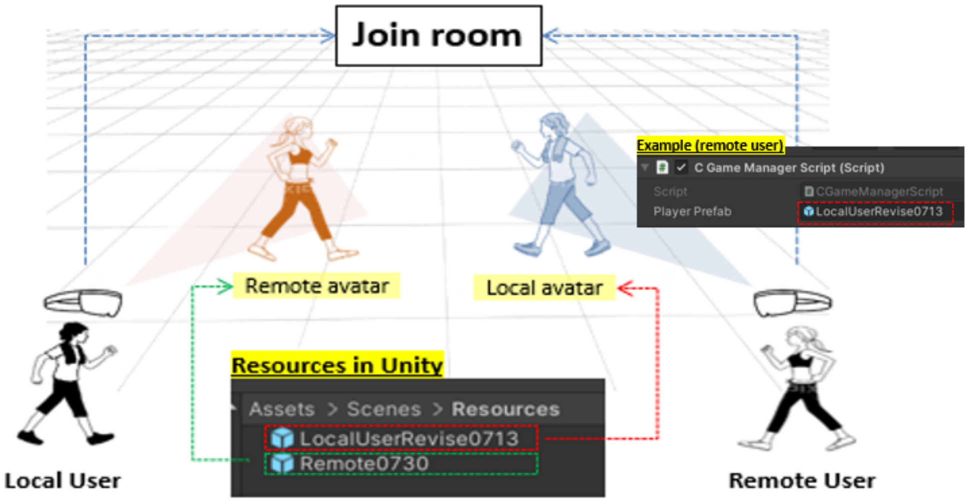


Figure. 5.11 Application of multi player game idea

The advantages and disadvantages of the current implementation are as follows:

- **Advantage**: The novel method of movement synchronization is used the camera position of the HMD and does not require separate sensors or equipment to capture the user's motion. In the case of walking exercise, the target of this study, hands-free user experience is essential for effective exercise. Thus, the novel method has the advantage that it is possible to provide a hands-free user experience and minimize the restriction of the walking exercise place issues. In addition, since the actual walking motion is applied to the avatar's motion, the most frequent user behavior that can be expressed in the walking motion can be faithfully expressed in this implementation.

- **Disadvantage**: In the current stage, the system can only implement basic motions such as walking, stopping and idling. That is, when the user's HMD moves, the avatar starts walking at the same time, and when the HMD stops, the avatar stops and displays an idling motion. Although the study is targeted relatively predictable user's behavioral patterns of walking. However, if this study is expanded, there is a possibility that more synchronization of various motions might be required.

5.5.3 Real-time Voice Chat between two Users

Our system provides real-time voice chat between local / remote users. It is a feature that can improve the sense of the presence of remote users by providing auditory feedback along with visual feedback through the avatar. Real-time voice chat is implemented using **Voice for PUN2**. As hardware, it is implemented through the voice microphone and speaker of HoloLens 2. Real-time voice chat is implemented by applying the component provided by Voice for PUN2 to the avatar. Apply Phothon *Voice View, Recorder, and Speaker* components to each avatar. (see **Figure. 5.12**)

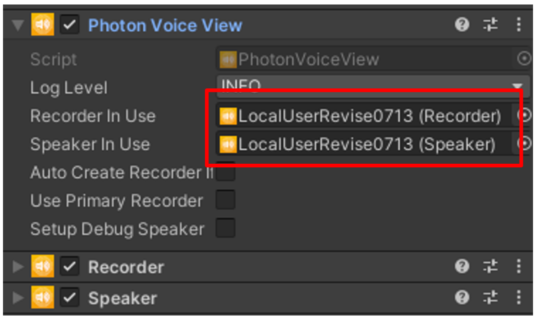


Figure. 5.12 Settings of Voice for PUN2

5.5.4 Direction Control of Avatar by Tracking of User's gaze

Our system uses a method of tracking the user's gaze to control the direction of the avatar. **Figure. 5.13** shows the editor view, the yellow line represents the user's gaze. When the user's gaze moves, the avatar follows the yellow line. It is a method in which HoloLens 2 becomes the controller and controls the direction of the avatar.

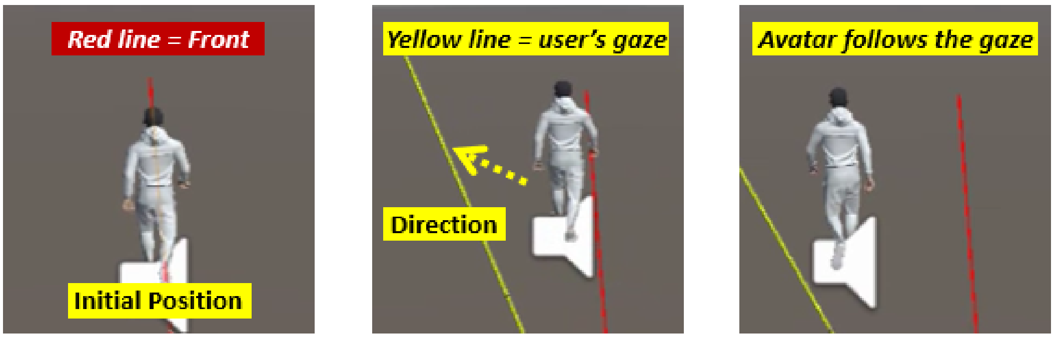
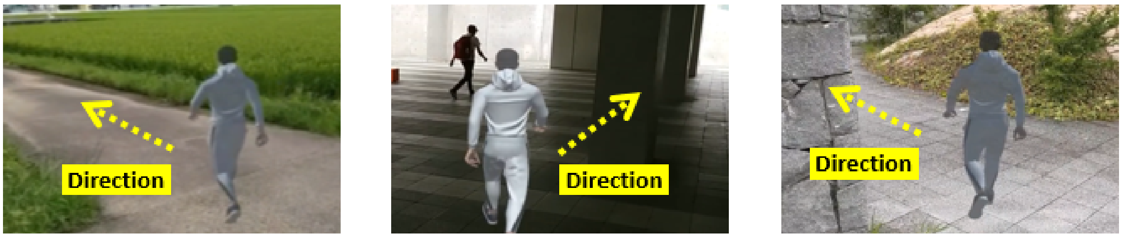


Figure. 5.13 Tracking of user's gaze for direction control in editor view.

This is because the recognition of the progress direction while walking exercises is most directly and intuitively performed from the user's gaze. While user walking exercise, the gaze of the user with wearing the HoloLens 2 coincides with the direction of the camera of HMD. Thus, the change in the user's gaze coincides with the direction and angle the camera is pointing. It is implemented using *Follow* among MRTK components. It is a feature that a digital object tracks the camera position according to the change of the camera.



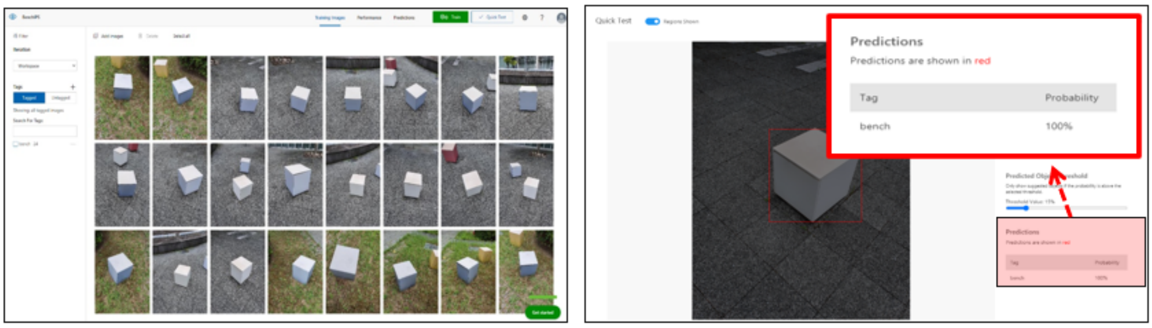
* *All images were taken from HoloLens 2*

Figure. 5.14 Several tests of direction control on random course

Figure. 5.14 shows the result of actual use on the random course. Aforementioned, we implemented the direction control of the avatar by applying the interface that users can understand most intuitively. We confirmed that the avatar moves naturally along with the user's walking through this method through the test. In addition, if the use of A.I. technology is possible in the future, the system may consider the ability to self-analyze and identify a course that can be walked. We considered the course identification method using A.I. in the development stage. Currently, road segmentation and detection, which are mainly used in autonomous vehicle research, etc., were attempted. During the development process, we succeeded in classifying the road based on the line in the 2D video input through the solution. However, we confirmed the disadvantage of not being able to identify properly in places where the physical line is not clear. This task required more powerful computing not only HMD. Since required separate computing is not the task of the current study, it was left as a future task.

5.5.5 Sitting on the Bench by Object Detection

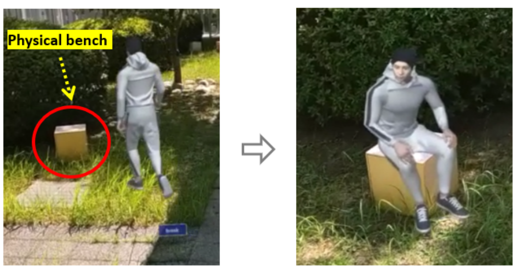
Object detection is used for the interaction of the avatar with a physical object identified within the user's FOV. In our system, Microsoft Azure Custom Vision is used for object detection. It is an image recognition service that allows to build, deploying, and enhance own image identifiers. In our system, the physical bench located on the walking course is implemented. For implementation, we uploaded more than 15 images of the physical bench. And after training on the Azure Custom Vision, the prediction is tested with the same bench image, and it is confirmed that the bench is identified well. (see **Figure. 5.15**)



Training of physical bench image **Prediction result *(100%)***

Figure. 5.15 Training of image of physical bench and prediction result

** All images were taken from HoloLens 2*



Detection of physical bench **Sitting on the bench**

Figure. 5.16 Sitting on the bench

Object detection feature is used for realistic interaction between the virtual partner avatar and the real world in our system. This feature implemented in the system identifies the physical bench on the walking course, e.g. when a user sits on a bench for the purpose of rest during a walking exercise, the physical bench is recognized by object detection so that the avatar can sit on the physical bench together. A trained model by Azure Custom Vision can be displayed through the published WebAPI using HoloLens 2's camera capabilities. However, in this implementation, we implemented sitting on bench interaction using a scanned 3D space for robust implementation.

5.5.6 Collision with Physical Object

In our system, collision with physical objects is implemented to enhance the real sense of the presence of the avatar as a virtual partner. The avatar provides visual feedback to the user when the avatar collides with a physical object, e.g. a wall, barriers, etc., during walking exercise. This interaction can be expected to have not only the effect of foreseeing risks to the user, and but also improving the sense of the presence of virtual partners for users.

Algorithm 2 Changing avatar action by collision with physical object.

Require: Visual feedback by collision with physical object
$Y \leftarrow AvatarCharacterController$
$X \leftarrow ColliderofPhysicalobjectbySpatialAwareness$
if Collision(X, Y) **then**
  $SetParameter \leftarrow$ **REACTION** ▷ *First reaction*
  $SetParameter \leftarrow$ **TURN TO THE USER**
  $SetParameter \leftarrow$ **SHAKE HEAD** ▷ *First reaction*
else
  No action change
end if

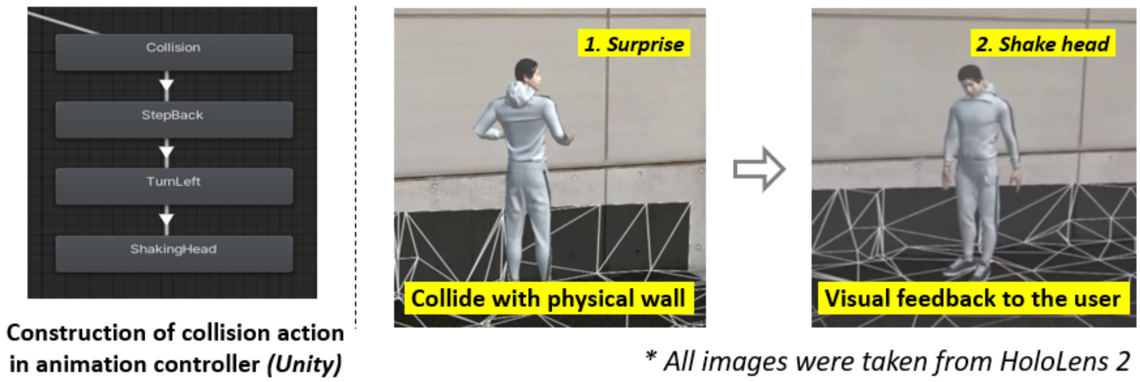


Figure. 5.17 Collision with physical wall and visual feedback

The implementation of the collision in the system is represented by the collision of the collider of the avatar with the physical space identified based on *Spatial Awareness* feature using the HoloLens 2 camera. In Unity, we can assign the *Character Controller* component to the avatar. It detects the collisions between avatars and other objects with colliders. And then, the avatar animation state change according to collision, it is applied by C# script. (see **Figure. 5.17**)

5.5.7 AR directional Indicator out of Field of View.

In our system, the position of the avatar can be freely located, e.g. front, alongside, and behind of user. However, there is an issue where the location is not known when the avatar is outside the user's FOV. If the avatar is located out of the user's FOV, a directional indicator implemented by Augmented Reality appears to intuitively indicate the avatar's location. The AR directional indicator is a tag-along component that orients itself to the direction of the desired point in space.

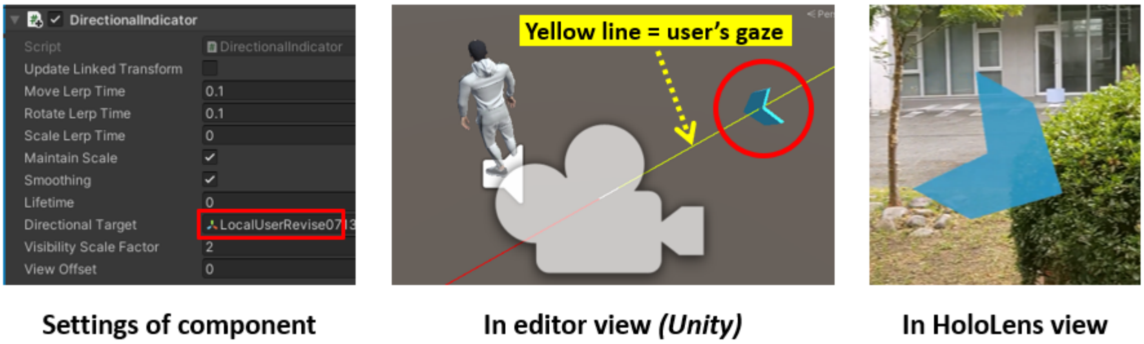


Figure. 5.18 Implementation of AR directional indicator

AR directional indicator is implemented by applying the *Directional Indicator* component provided by MRTK. At this point, an avatar is assigned as a corresponding directional target. **Figure. 5.18** shows the editor view, the yellow line is the user's gaze. If the yellow line is facing in a different direction from the avatar, it means the avatar is located in out of FOV, a directional indicator is displayed as shown in the middle image. In this case, the direction of the arrow points to the position of the avatar. In addition, we can adjust the tracking speed, rotation, and size of the indicator through various lerp time settings.

5.5.8 Comparative Walking by 3D Space Scanning

In the routine course, we conducted 3D space scan using LiDAR sensor to implement comparative walking interaction with an avatar who has a user's previous walking record. The scanned 3D space is imported into Unity. And then, we designated the user's walking course by setting way points on the scanned 3D space. As a next step, we create an avatar that has the user's previous walking record. It can compare with the current user's walking speed as a pacemaker to implement comparative walking interaction. In our system, the previous date is displayed on the top of the avatar's head as text. User can intuitively perform the walking exercise while comparing the previous record of the walking exercise. Because it is not just showing the previous record as a number, but the user can experience physical walking together with their own previous records. In comparative walking, multi avatars can be created and compared with records of various record. The avatar improves the user's walking experience as a pacemaker. The recording of walking exercise data in this system utilizes an existing smartphone application. However, there is no direct connection between the smartphone application and this system, and it is implemented in a way that is assigned in advance before build an application for HoloLens 2. (see **Figure. 5.19**)

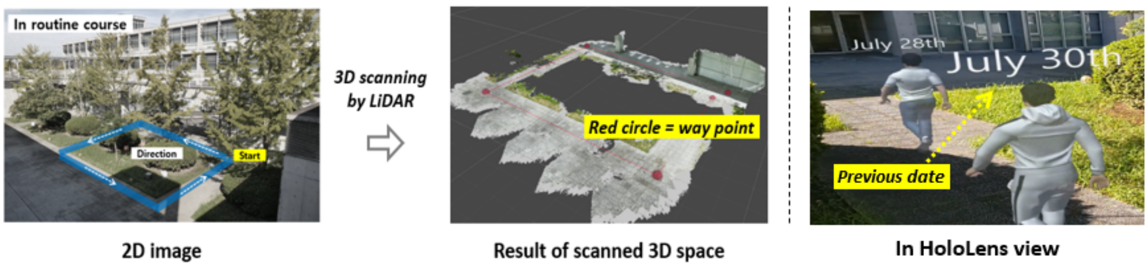


Figure. 5.19 3D space scanning by LiDAR and set way points in routine course

Figure. 5.20 LiDAR in iPhone 12 Pro

The course is scanned using a LiDAR sensor. LiDAR is a method of determining a range and variable distance by aiming at an object with a laser and measuring the time it takes for the reflected light to return to the receiver. We used the Area Target of the Vuforia engine. We downloaded the Vuforia Area Target Creator app from your iOS device with a LiDAR scanner. We used the LiDAR sensor in off-the-shelf *iPhone 12 Pro*. Then, we scanned the surrounding space with the app's 3D scanning technology and import the digital model to create an Area Target Database. The output of the scanning process is imported into the Area Target Generator, which returns a dataset file, mesh, and Unity package set.

5.5.9 Competition with Avatar

In our system, user can compete with the avatar through the simple rule such as the first comer wins the competition. In addition, the avatar can be represented emotion depending on the result of competition.

Algorithm 3 Competition between user and AR 3D avatar.

Require: Avatar represents different emotional action by the competition result

$Y \leftarrow Goal'sCollider$

$X \leftarrow Avatar'sCollider$

$Z \leftarrow HoloLens2'sCollider$

if Collision(Y, X) **then** ▷ *Avatar win*

  $SetParameter \leftarrow$ **VICTORY**

else if Collision(Y, Z) **then** ▷ *User win*

  $SetParameter \leftarrow$ **DISAPPOINTED**

end if

For implementation, we assigned a collider to the object representing the competition goal. Based on the collision of the collider, the result is judged by the following two cases. ***(1)*** Avatar collider collides with the goal's collider first, the system determines that the avatar arrives at the goal first. Then, the victory action of the avatar is executed. ***(2)*** HoloLens 2' collider collides with the goal's collider first, the system determined that the user arrived the goal first. Because the user is wearing the HoloLens 2, the movement of the camera means the movement of the user. Then, the avatar stops walking and performs the disappointing action.

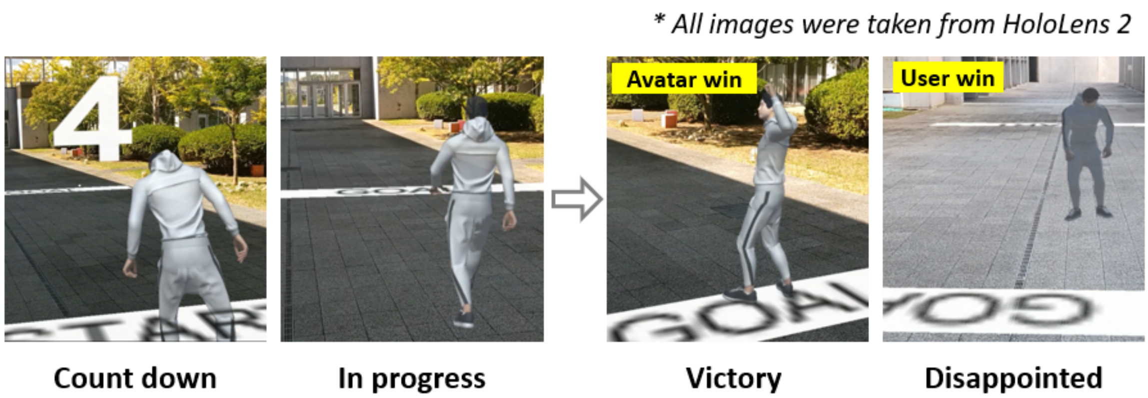


Figure. 5.21 Competition with avatar and emotional action by the result

5.6 Interactions for Encouraging User

Two types of encouraging interactions are: *(1) Clapping for the user:* If a certain distance between the avatar and the user occurs, the avatar can clap to the user for encouraging, *(2) High-five with avatar*: If walking exercise passes for a certain amount of time, user can high-five with the avatar.

5.6.1 Clapping for User

Our system can recognize the distance between avatar and user. If a certain distance without stop command during the walking exercise, the system determines the pace of the user's walking exercise decreases which means the walking exercise motivation is insufficient.

Algorithm 4 Clapping action based on the distance between user and avatar.

Require: Changing the avatar's action to the clapping action

$Y \leftarrow AvatarPosition$
$X \leftarrow UserPosition$
if $X - Y \geq CertainDistance$ **then**
    $SetParameter \leftarrow$ **STOP WALKING** ▷ *Changing animation state*
    $SetParameter \leftarrow$ **TURN TO THE USER**
    $SetParameter \leftarrow$ **CLAPPING**
else if $X - Y \leq CertainDistance$ **then** ▷ *The distance restored*
    $SetParameter \leftarrow$ **STOP CLAPPING**
    $SetParameter \leftarrow$ **BACK TO THE IDLING**
end if

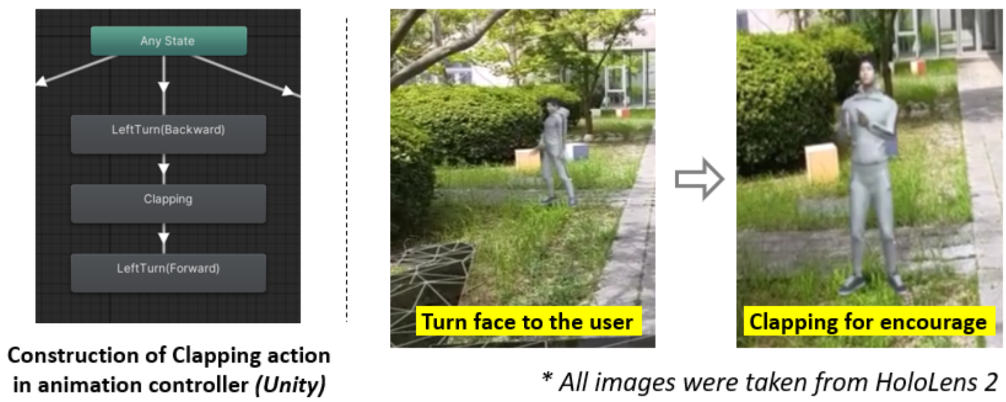


Figure. 5.22 Clapping action for encouraging

Accordingly, the avatar stops the walking action, and turn faces to the user, and then gives encouragement through the clapping action. At this time, visual and auditory feedback is provided. And then, when the user approaches again and the distance is restored, the avatar changes action back to the idling state.

5.6.2 High-five with Avatar

Our system can determine that the user's fatigue has accumulated when a certain amount of time has passed based on the duration of the system of use. High-five interaction is designed between the user and the avatar in order to arouse the interest of the user and give enjoyment to the user. The interaction between the user and the avatar is implemented using a touch interface. When high-five success, visual and auditory feedback can be provided.

Algorithm 5 High-five interaction between user and avatar.

Require: Implementation of high-five with avatar by touch interface

$Y \leftarrow Durationofsystemofuse$
$X \leftarrow User'shandmesh$
$Z \leftarrow Colliderofpartofavatar'sbody$
if $Y \geq CertainDuration$ **then** ▷ *System determines user's fatigue*
  $SetParameter \leftarrow$ **STOP WALKING** ▷ *Changing animation state*
  $SetParameter \leftarrow$ **TURN TO THE USER**
  $SetParameter \leftarrow$ **RAISE AVATAR'S HAND**
  if Collision(X, Z) **then** ▷ *Between hand mesh and collider*
    $SetParameter \leftarrow$ **JOY**
    AudioSource.PlayEffectSound
  end if
end if

Figure. 5.23 High-five between user and avatar.

HoloLens 2's camera can recognize the user's physical hand. Recognized results of the hand are displayed with Augmented Reality mesh. The touch interface between the digital object, i.e. avatar, and the physical hand uses MRTK's *Near Interacion Touchable* and *Hand Interaction Touch* components. We can apply the collider to the part of the avatar's body to be touched. If the touch is successful, the animation state of the animation controller is changed to provide visual feedback. The auditory feedback is implemented by assigning the sound effect to the *Audio Source* component and assigning the corresponding audio source to *On Touch Started* of *Hand Interaction Touch* component.

Chapter 6

Preliminary Evaluation

We conducted a preliminary evaluation to evaluate our system performance with participants and survey for participants' perception including behavior. Our key interest is to obtain the feedback from the participant. We qualitatively and preliminary evaluated the participants' perceptions and opinions about the system. Through the user study, we analyzed the result of the initial level of evaluation and confirmed issues as a future work.

6.1 Participant, Method and Procedure

We recruited 8 participants *(6 males, 2 females)* with an age range the 20s to 30s from 6 graduate students of Waseda University who have experience with Augmented Reality and 2 ordinary people who have inexperience with Augmented Reality. For participants without Augmented Reality experience, the basic usage of HoloLens 2 was explained before the system experiment.

The method of preliminary evaluation was that experiencing the system and filling out a given questionnaire. We conducted the experiment in groups of two people. The experiment for each team took about 1 hour. The above time was appropriate for those with Augmented Reality experience, but it was somewhat lacking for those who did not. We provided a demo video(5-min version) to the participants in advance to give them a rough understanding of the system. All participants wore a HoloLens 2 and experienced all of the two use cases. We observed and recorded participants' behaviors and comments during the user study. After the questionnaire was completed, a brief interview was conducted with the participants. Since this preliminary evaluation is a qualitative evaluation, specific measurements of usage time and walking distance were not carried out. The place of the experiment was conducted outdoors. First, we tried to confirm the understanding, experience, and interest of the participants in the overall system through this evaluation method. And we analyzed it after conducting a survey on the focus of evaluation.

The detailed procedure of the experiments is as follows. Participants were given a brief introduction of the study and followed by two phases. Participants experienced Phase #1 followed by Phase #2. Participants were asked to complete the questionnaire and brief interview after the user study.

- **Phase 1 (Case #1)**: All participants customized appearance of the avatar, e.g. oneself or friend. And participants wore a HoloLens 2 and performed a walking exercise while interacting with an avatar using the system interface.
- **Phase 2 (Case #2)**: Organize two people in one team and divided into local / remote user in each team. Hardware settings were the same as phase 1, but needed a smartphone for a portable Wi-Fi hotspot. Participants performed a walking while seeing a partner-appearance avatar. The movement of the avatar was synchronized by the remote user and real-time voice chat was provided.

The questionnaire consisted of case-specific questions and common questions for both cases. The answer to the questionnaire consisted of five ratings. Users watched the implementation demo *(5-minute version)* in advance to understand the system. We conducted questionnaire composition and response analysis using *Google Form* (A survey management software included as part of free web-based supported by Google Docs editor). Participants could respond to the questionnaire ranging from the most negative level 1 to the most positive level 5.

6.2 Result

We present the analysis of the results from preliminary evaluation of our system. We analyzed following five points of our system; ***(1) Usability***, ***(2) Sense of presence***, ***(3) Novelty***, ***(4) Effectiveness***, and ***(5) Continued use of system***, based on result of questionnaire response and observation of participants behavior and interview. Detailed contents of the questionnaire are as following:

1. Do you think this system easy to use?
   (User only need to wearing HoloLens 2 (AR HMD) and having smartphone.)

   (Negative) 1 2 3 4 5 (Positive)

2. Do you think a 3D personalized avatar implemented in Augmented Reality recognized as a virtual partner?

   (Negative) 1 2 3 4 5 (Positive)

3. In case #2, do you think you can feel walking with remote user using partner-appearance avatar which synchronized by remote user's movement?

   (Negative) 1 2 3 4 5 (Positive)

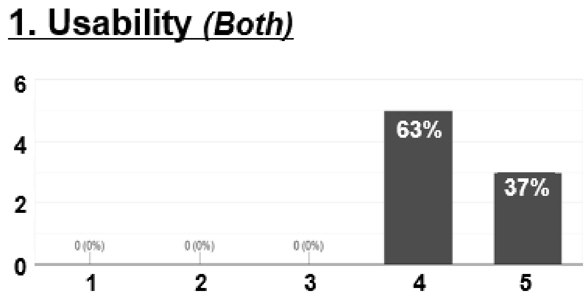
4. Do you think this system is effective for increase the motivation?

   (Negative) 1 2 3 4 5 (Positive)

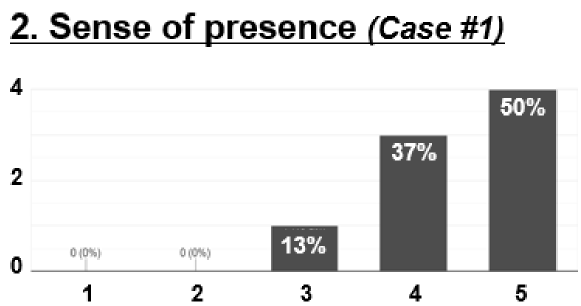
5. Do you think you want to use this system again?

   (Negative) 1 2 3 4 5 (Positive)

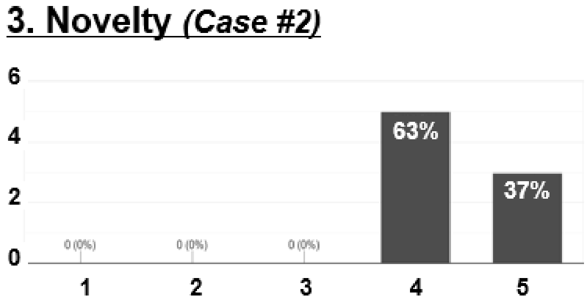
The analysing results according to each question are as follows:



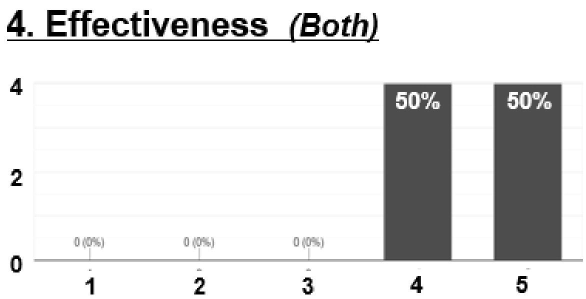
- **The first question** was about the usability of the system for both use cases. It was analyzed whether the participants could intuitively understand the system. In particular, we emphasized that only HMD (Microsoft HoloLens 2) and a smartphone are used as the hardware. However, users who have no experience of using HMD need time to adapt to basic operation. We found most of the participants answered positively.



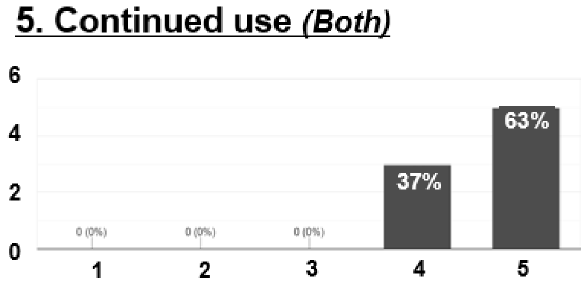
- **The second question** was about the sense of presence in Augmented Reality 3D Avatar for case #1. It was analyzed participants' perceptions of the appearance and behavior of avatars implemented as a virtual partner. We believe that system effects may differ depending on the degree of the real sense of the presence of the virtual partner. In our system, an avatar in human form is provided. As can be seen from the results, we found that some participants were not positive about the actual presence of the avatar. We recognized the need to design various behaviors and interactions of avatars as an important future task to improve actual presence.



- **The third question** which corresponds to the case #2, is about the novel method of movement synchronization. We emphasized that it is a method of using the camera coordinates of the HMD (Microsoft HoloLens 2) without extra sensors and equipment. We analyzed participants' perceptions of the designed the method. We found most of the participants answered positively.



- **The fourth question** corresponds to both cases. The purpose of this study is to analyze whether the designed Augmented Reality system is effective in increasing the motivation of walking exercise. We emphasized the proposal of a novel type of interaction in the walking exercise scene. We found most of the participants answered positively. In this evaluation, we inquired about the effect of using the system on the increase of motivation for walking exercise. We have not measured the improvement of the actual exercise effect such as duration, the distance of walking exercise. The evaluation of the exercise effect will be carried out as a future task.



- **The fifth question** is about the continued use of the system for both cases. We found most of the participants answered positively. And we believe the future task of developing interfaces and interactions to keep users interested.

In addition, we found the following comments from the quick interview and observation of participants. There were comments from all participants, but only meaningful comments related to the evaluation are summarized:

- **Participant 1**: *"I felt the avatar a little late stopped after listen the user's talking to 'Stop'. The last touch the high-five scene very good."*

- **Participant 2**: *"If I keep a pet dog, when the scheduled walking time, the dog becomes exciting that will make me have a walk with it. Or I suddenly receive an invitation from my friend, it is more effective to make me walk."*

All of the results in this preliminary evaluation are qualitative, thus a quantitative evaluation will be added in the next evaluation. In the future, we plan to measure an increase in the duration of walking exercise and walking distance with or without the system. During and after the user study, we observed the participants' behavior and interviewed them. The results of observation are as follows:

- We observed that most participants were more interested in case #2, which is walking with the remote user. We interviewed most of the participants were interested in the system and evaluated it positively.

- However, our system still has a somewhat awkward movement of the avatar, in particular, communication between the avatar and the user was rather one-sided, i.e. only designated interactions were possible. Some participants requested to add more diverse interaction with the virtual partner in the walking exercise scenes.

6.3 Discussion

We believe that our system is expected to increase the motivation of walking exercise as a result of preliminary evaluation. However, we found several issues and limitations as an initial stage of the system. The followings are the discussion issues:

1. **HoloLens 2 for walking exercise**: First, people already use many wearable equipment or devices for physical activity. In particular, we believe that the wear of sports goggles has a common with wearing the HMD so that dislike will be minimized. Second, we present the results of comparing the weights of the devices. It can be seen that the weight of HoloLens 2 is significantly disadvantaged compared to the average weight of 556g and sports goggles of 35g. However, compared to the 300g safety helmet used at the construction site, the weight of the HoloLens 2 can be inferred that people can wear it for a long time. Third, the target of this study is walking exercise. Because walking is different from running, we believe that there will be no limitation in body movement caused by the HoloLens 2.

2. **Unexpected movement of avatar**: As a result of the user study in Case #2, we found unexpected movements of the avatar. We analyzed the reasons for the following reasons. First, in order to place the avatar in the physical space in our system, we used the Spatial Awareness of HoloLens 2. The reason is that the time difference between the display of the avatar and the space calculation occurs due to the limitations of HoloLens 2 computing. Second, our system used the coordinate system of the HoloLens 2 camera to synchronize the movement of the avatar and the user. Since the prototype uses only the Z value of the 3D coordinate system, thus, when the user's

the X and Y axes are changed, it is necessary to calibrate the Z value required for the movement of the avatar. However, since the calibration value is not applied at this stage, thus, the unexpected movement appears. (see **Figure. 6.1**)

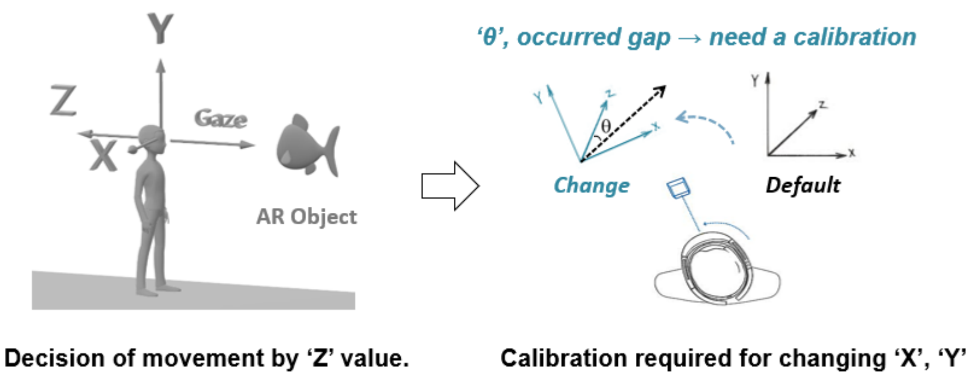


Figure. 6.1 Unexpected movement of avatar by non-calibration

3. **Restricted interaction with avatar**: We found that the interaction between the user and the avatar is relatively one-sided. The interaction implemented in this prototype system allows the user to interact with the avatar only through the situation and interface specified in advance during the development process. Thus, depending on the situation, the user may feel that the virtual partner is acting out of context. The limitation is that it is difficult to require complicated calculations in real time by using only the computing of HoloLens 2. Therefore, it is necessary to consider the combination of advanced devices and technologies into the system.

In addition, two participants *(2 female, both are inexperienced of Augmented Reality and 20s aging range)* experienced as a prototype test of our system in case #2 for broadcasting of RKB MAINICHI BROADCASTING CORPORATION. We did not evaluate or analyze the above tests. After the pilot test, we confirmed the following observation results. First, for users with no Augmented Reality experience, a basic tutorial on device usage and the interface was required. Second, it was confirmed that the voice recognition interface of this system responds to ambient noise other than the user. Lastly, when using the HoloLens 2 in outdoor, it was confirmed that the visibility issues depend on the light conditions.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

We designed an Augmented Reality system for increasing users' motivation for walking exercise. Specifically, 3D Personalized avatar was implemented as a virtual partner in Augmented Reality. We designed a novel interactions that user enables realistic walking experience with a virtual partner. In case #1, we designed interactions between user and avatar. And in case #2, for the simultaneous walking experience between users who are in long-distance remote locations using the avatar, we designed a novel method of movement synchronization between user and avatar using only HMD without extra sensors.

We investigated the effect of 3D personalized avatar in Augmented Reality as a virtual partner to increase the motivation of walking exercise. As a result of the preliminary evaluation of the system, most of the participants evaluated the system positively. The results support the idea that novel interactions in walking exercise scenes between user and avatar can increase the motivation of walking exercise. In our preliminary evaluation with participants, each participant showed the interest and potential of our system to make repetitive physical world walking exercise more entertaining. In the future, we plan to investigate a quantitative evaluation, e.g. comparing the duration and distance of walking exercise with or without our system. This is because the two factors are important for confirming the user's motivational increase.

7.2 Future Work

The future work of this study is derived from the results of reviewing the system design, implementation, and preliminary evaluation. The purpose of future work is to enhance the achievement of the research goal through system improvement and to expand this research by discovering and applying novel ideas. We plan the future work focusing on the following issues:

- **Refine system using extra technology and device**:

  Currently, the interaction of this system is limited to those specified in advance in the development stage. Thus, the direction of communication is recognized as one-sided depending on the separate user's experience. Additional computing is required for the avatar to understand the real-world environment and context. Alternatively, a combination with Artificial Intelligence (A.I.) technology could be one way. Unfortunately, we tried to implement road detection and segmentation based on A.I. technology in this study, but we failed. The above method is used in research on autonomous vehicles and is technology necessary to accurately separate the type of road from the image input to the camera for the safe movement of the vehicle. In this system, the actual walking course input to the HMD camera was determined to be a walkable and a non-walkable road in real time, and the goal was to give feedback to the user. However, the implementation has not been successful yet. Thus, we will continue to investigate the solution.We consider hardware design for the user's hands-free experience. However, if powerful computing is required in future work, additional devices may be considered. In priority, we consider the first is to use the computing of the smartphone. We can also think of ways to utilize small computing, e.g. wearable devices, computer stick [53], and small computers such as Arduino.

- **Improvement of unexpected avatar movement in case #2**:

  In Case #2, an unexpected movement of avatar problem occurred. We mainly identified two problems: ***(1)***Lack of the movement synchronization accuracy, ***(2)***Avatar do not placed properly on the physical space. To solve these problems, first, as a software approach, when developing in Unity, set an invisible virtual floor in the scene, and add a rigid body component to the avatar, which enables to apply gravity to the avatar, then the avatar could exist on the invisible virtual floor. And next, one of the reason is the time difference between digital contents display and calculation time of spatial awareness by HoloLens 2. What can be expected is that AR HMD will have more powerful computing power than now is released according to the hardware development and device technology improvement. This is because HMD's computing alone will cover more processes.

- **Implementation of avatar more than two**:

  According to the interview results of the participants in the preliminary evaluation, there was an opinion that it would be desirable to have more avatars. We could consider implementing two or more avatars. In particular, in the case of Case #2 implementation applying the multiplayer game concept, we expect that multiple users will be able to access it simultaneously.

- **Quantitative evaluation of system**:

  The preliminary evaluation conducted in this study was a qualitative evaluation. As a future work, the quantitative evaluation will be conducted to prove the system could increase the motivation for walking exercise. Specifically, ***(1)*** Change in duration, ***(2)*** Change in distance, are compared with or without this system. The above evaluation results demonstrate the hypothesis that the use of our system will increase the amount of change and also support the purpose of this study that the system could increase the motivation for walking exercise.

We will improve our system and the achievement level of the research goal by solving future works. In addition, we will consider various related studies and improvements of evaluation methods to investigate the fact that the application of Augmented Reality to the walking exercise scene and presenting a new interaction improves the user's experience and increases the motivation of walking exercise.

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