Increasing Motivation of Walking Exercise Using 3D Personalized Avatar in Augmented Reality

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Abstract. Walking is an easily accessible and effective exercise, hence it can be easily participated as a part of a person's everyday. However, due to changes in our social environment such as the increase in single-person households, hectic lifestyles and an unprecedented pandemic, the number of people who walk alone is increasing. We found that people lack motivation when they walk alone; to address this, we designed an interactive full-body 3D personalized avatar in augmented reality (AR) as a virtual walking partner. Our research goal is to increase the motivation of walking exercise using an AR 3D avatar. This approach focuses on the social aspects of physical exercise, that is, cooperation and competition with a partner. The proposed system has two types of use cases: (1) walking with an avatar, and (2) walking with a remote user using an avatar. We investigated the effect of designed interactions with a virtual walking partner for both cases. In addition, we designed a method of movement synchronization between a user and an avatar using only a head-mounted display (HMD) without separate sensors. The preliminary evaluation of the system indicated positive response from participants. We believe that our findings support the idea that designed interactions with a virtual walking partner can increase a person's motivation of walking exercise.

Keywords: Augmented Reality · 3D Personalized Avatar · Motivation for Walking Exercise.

1 Introduction

We explore a future in which people spend more time using augmented reality (AR) technology, even during activities of everyday life. We are interested in how AR technology can improve the human experience [1, 2] regarding physical activity. Walking is an easily accessible and effective exercise, so it can be easily participated in person's everyday. However, due to the change of social structure and environment, for example, the increasing numbers of single-person households, hectic lifestyles and an unprecedented pandemic, the number of people who are walking exercise alone is increasing [3]. Additionally, we have identified a problem in that people often have lower levels of motivation for walking exercise when doing it alone. Therefore, in this paper we propose an AR system to address the lack of the motivation issue in walking exercise. We believe that existing methods, such as devices and applications for walking, have limitations. According to the related studies in physical exercise [3, 4], motivation is usually generated when exercising with a partner or group. Thus, in this study, we focus on the social aspect of exercise to increase a person's motivation in terms of walking exercise [5] (i.e., cooperation or competition with a partner). In short, we aim to provide the sense of walking together experience with a virtual walking partner to overcome the limitations of time and place. In our research, AR technology was applied for the realistic interaction with a virtual walking partner.

2 Related Work

Since there have been few related works that have studied the use of an AR 3D avatar as a virtual walking partner, we investigated and analyzed related studies that featured relevant topics and keywords in the following categories: social aspects of physical exercise, AR and mixed reality (MR) for motivation, interactive virtual full-body 3D avatar and walking support in AR.

2.1 Leverage of Social Aspects in Physical Exercise

Previous research has also investigated the social aspect of physical exercise. We designed interactions that the user can walk while cooperating and competing with a virtual walking partner. Hanson and Jones [6] studied the motivation generated by being part of a group, which encouraged healthy behavior in participants and inspired positive physical activity. It has been proven that regular walking exercise can contribute to people's well-being life [7]. Other studies have confirmed results the positive effect of cooperation with walking partners or groups [8]. For example, Futami et al. [9] presented a competition system using the number of steps of a participant and confirmed a positive effect of competition factors on walking motivation. Based on these social effects related to physical exercise, in this study, we attempt to increase walking exercise motivation through interactions with a 3D avatar as a virtual walking partner.

Additionally, in our system, an individual who has access to walk in a long-distance remote location can experience the sense of walking together with a partner in separate location using the avatar. To share the walking experience with remote user and make it more realistic, various methods for recognizing a user's gait have been studied [10, 11]. For example, Baldi et al. [3] presented a method of using a wearable device to share a walking experience with a person located in a remote place. The user could experience the walking of the remote user through the vibrations of the wearable device. However, unlike these studies, our study provides visual feedback through an AR 3D avatar which can provide a more intuitive walking exercise experience. Since the positive effects of being with a group or partner during physical activity have been confirmed in previous studies, we utilized the two factors of cooperation and competition using the realistic sense of presence in the avatar.

2.2 Effectiveness of Walking Partner

We designed a virtual walking partner using a 3D avatar. The proposed 3D avatar was implemented in the form of a full-body human shape. Previous studies on the implementation and effect of walking partners can largely be divided into two categories: with physical partner and virtual partner. Karunarathne et al. [5] presented a humanoid robot as a walking partner and conducted a study on the effect. The results suggested that participants rated walking with robot partner higher than walking alone, and the robot as a walking partner was found to alleviate the loneliness of users walking alone or to increase the effectiveness of exercise, and even medical effect [12, 13]. These studies confirm the positive feedback on the effects of walking partners.

Virtual reality (VR) and AR technology is the most common method used to realize a virtual partner. In this study, we realized a virtual walking partner using AR technology. Norouzi et al. [14] presented walking with a virtual AR dog as a partner and investigated participants perception and behavior. The findings showed that the experience with the AR dog as a companion changed participants' behavior and social interactions with other people who could not see the dog. We believe this is also confirms the effectiveness of virtual objects as partners. Above all, the research outlined in these sections supports the fact that interactions with virtual objects can affect a user's emotionality. However, we believe that the effectiveness of a virtual partner depends on how realistic it is; this requires not only visual information, but also the sense of being together. Nevertheless, there are still many awkward interactions with the real space that go beyond physical common sense of the human's perception. To overcome these limitations, Kim et al. [15] investigated and designed an effective method for the implementation of visual effects that decreased collisions between AR virtual humans and real objects. Additional studies have also attempted this, with approaches such as applying visual effects and psychological improvement methods to improve a user's AR recognition effect [16, 17]. The system proposed in this paper is designed so that the user can interact with the avatar through an intuitive interface, assuming various situations that may occur while walking exercise.

2.3 Interactive Full-body 3D Avatar in Augmented Reality

To create a realistic sense of presence of partner, we designed a full-body for the 3D virtual walking partner, with realistic appearance and physical conditions. Related studies, which use avatars mainly for the purpose of remote collaboration, found that virtual avatars had a positive effect on cooperative work. To create an avatar with an appropriate shape, we considered previous research into the optimal shape of an avatar. The effectiveness of using 3D model in AR has been studied in the domain of education and it applied to physical education and sports. For example, Chang et al. [18] presented the effectiveness of a 3D model in physical education. Unlike the video-assisted instruction method, their system provided interactive feedback to learners using an 3D AR model. Koulouris et al. [19] investigated the effectiveness of three types of avatars in VR exergame system: generic, realistic, and idealized avatar. Praetorius et al. [20] presented the effect of the shape of an avatar according to context. The above studies confirm that an avatar that is of a human shape is preferable in the context of an interpersonal relationship. Thus, we believe the shape of an user-friendly avatar as a walking partner is a significant factor in increasing the effectiveness and motivation of walking exercise.

3 Research Goal and Approach

The goal of this research is to increase an individual's motivation of walking exercise using a 3D avatar. To achieve this, we designed an interactive full-body 3D personalized avatar in AR as a virtual walking partner. We designed the avatar to behave like a real human. In addition, to provide a simultaneous walking experience between two remote users, we designed a method to visually present the movement of a remote user using an avatar. Furthermore, we designed interactions by predicting events that may occur while walking exercising with a physical partner. Therefore, we aim to increase the user's motivation for walking exercise through the designed interactions.

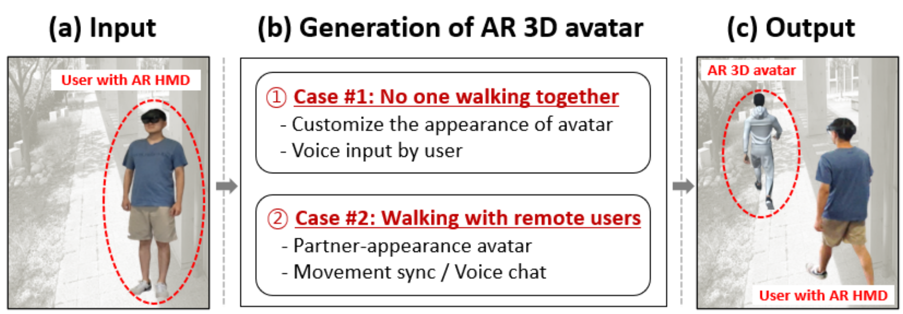

Fig. 1. Approach overview. (a) The input is a real scene, viewed through the AR HMD. (b) The generation of a 3D avatar depending on the case. Each case generates a different avatar appearance and action. (c) The output of the approach is the generated 3D AR avatar.

Fig. 1. shows the overview of the approach, which has three parts: (a) Input, (b) Generation of an AR 3D avatar, and (c) Output. Fig. 1(a) outlines the input of the model. This is a real scene, seen through the AR HMD. Next, as in Fig. 1(b), an AR 3D avatar is generated. The avatar's appearance and action depends on whether the user is walking alone or with a remotes user. Finally, the user can walk with a full-body 3D avatar as a virtual partner, shown in Fig. 1(c). AR technology is applied to ensure realistic interactions with the virtual avatar. The AR can expand a user's perception not only by simply showing additional

digital information but also by engaging their capabilities and emotions. Since an avatar's action can be changed by the user's voice input or by interaction with a physical object, we believe that the designed virtual walking partner can provide the realistic sense of presence as if walking together with the partner.

4 System Design

In our system, the existence of a physical walking partner can depend on whether they are able to share the same space at the same time. Hence, we designed our system based on two possible cases, depending on the presence and absence of a physical walking partner: Case #1, when a user does not have a physical walking partner in the same location; and Case #2, when a user has a physical walking partner who can walk together at the same time, but who is located in long-distance remote location. Both cases have a corresponding 3D personalized avatar. The avatar is expressed on top of the real world by applying AR technology. We believe that AR technology is the key to connect digital information and reality in a realistic manner. We designed interactions to provide the sense of walking together experience with a 3D avatar by providing a real walking experience with a virtual partner, rather than not just digital information in the user's line of vision. (see **Fig. 2**)

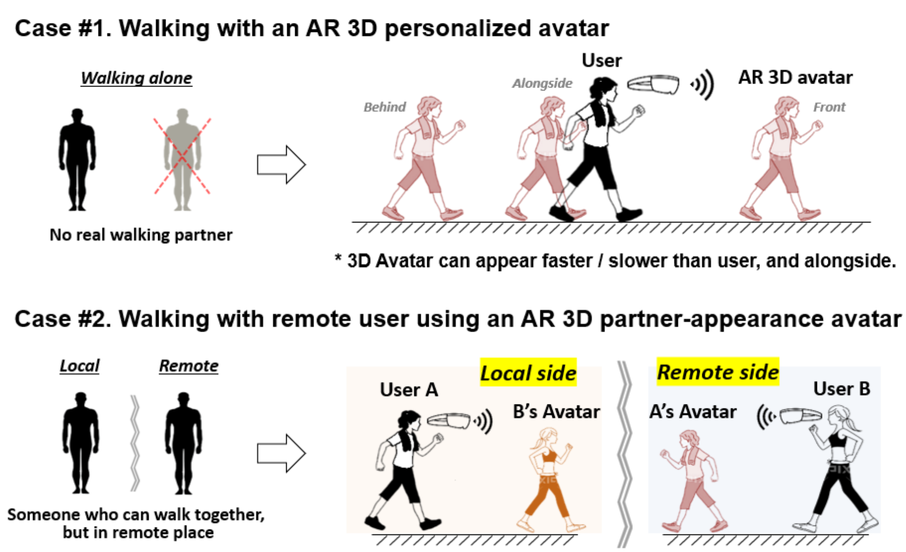

Fig. 2. The two cases of the proposed system: Case #1, in which a user is walking without a real partner; and Case #2, in which a user is walking with a real partner, but in long-distance remote.

In the proposed system, the user can select the interaction depending on the user's purpose, preference, or situation. In both cases, an AR 3D virtual partner is used due to the absence of a physical walking partner in the same physical space. We believe that the effectiveness of a virtual walking partner will be determined by the extent to which it can replace the role of a physical partner. Thus, we analyzed the design of interaction in the two possible cases in advance, to determine the best way to implement the 3D avatar to each situation.

4.1 Case #1. Walking with an AR 3D Avatar

In Case #1, a user can walking exercise with a virtual partner because a physical walking partner is not available. The virtual partner is a full-body 3D personalized avatar in the form of a human, implemented with AR technology for a realistic interaction providing the user with a real sense of presence. We believe that the user's motivation for walking exercise will be increased due to the realistic interaction with the virtual partner.

User can customize the appearance of the avatar, for example, to represent oneself or friends which can provide a better user experience [26]. The user can interact with the AR 3D avatar while walking together. Case #1 is divided into three types of walking interactions depending on user's walking purpose and preference: *Normal*, in which the user can simply walking exercise with the AR 3D avatar; *Pacemaker*, in which the user can engage in comparative walking with the AR 3D avatar, who has the user's previous walking information (to set a pace); and *Competition*, in which the user can compete with the AR 3D avatar with simple a rule, such as the firstcomer reach the goal wins the competition (see **Fig. 3**).

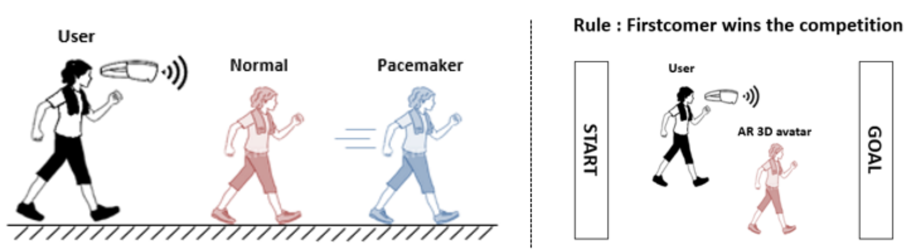

Fig. 3. Case #1 is separated into three types of walking interaction: Normal, Pacemaker, and Competition.

The three types of walking interactions represent situations that can occur during walking exercise with a partner in real life, and all were implemented for the purpose of increasing a user's walking motivation. In our system, the user can select a walking interaction type according to the user's walking purpose and preference. We designed appropriate behaviors and interactions for each situation. In addition, we designed an intuitive interfaces for users so that their walking exercise experience was immersive and so that they could interact with the AR 3D avatar using their voice input, gaze, and movement.

4.2 Case #2. Walking with a Remote User Using an AR 3D Avatar

If a physical walking partner exists, but is in a long-distance remote location, it is difficult to share the sense of walking together experience at the same time. Related studies on the simultaneous walking experience between remote users; for example, a method using auditory and tactile feedback was presented to simulate walking with a remote partner [3, 10]. However, the method proposed in this paper enables visual feedback by applying AR technology. Our system provides the walking together experience for local and remote users, using a 3D avatar for each user, which has the appearance of their walking partner. The movement of the avatar is synchronized with the remote user's HMD location data, and real-time voice chat is available between the two users. (see **Fig. 4**)

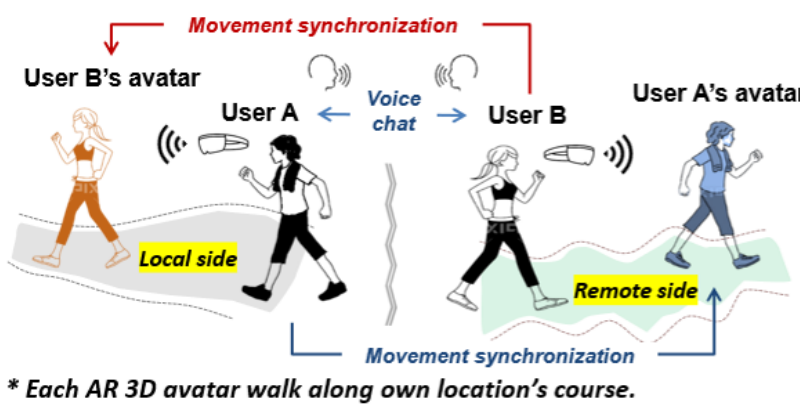

Fig. 4. In Case #2, each avatar's movement is synchronized with their respective user.

We designed a method to synchronize the movement of a remote user with that of an avatar, which can then be viewed by the local user. That is, the local user walks while watching the avatar move according to the movement of the remote user. We expect that the movement of remote users is visually provided through a 3D avatar as a virtual walking partner. It will provide an intuitive sense of mutual presence. In addition, this is supported by real-time voice chat that is available in our system. Through this, the user can recognize the movement of the remote user through the 3D partner-appearance avatar and while having a natural conversation with the remote user. Thus, we expect this interaction to increase both users' motivation for walking exercise.

We designed interactions to provide the sense of mutual presence [21, 22] to two users in separate locations. As a consideration, an avatar can only walk along the course of the corresponding user, regardless of the difference in course shape between users. In addition, different individuals' walking abilities, for example depending on gender or age, can be resolved by changing the walking speed of the avatar. Usually, the walking speed is different depending on gender or age. In our system, the avatar's different walking speed can be set by the user. This makes it possible for each user to walk at their own speed, while still viewing and interacting with the unique characteristics of the partner in the form of avatar.

4.3 Social Aspects of Interactions in Walking Scene

One of the effects of having a walking partner is having others pushing oneself to do one's best, that is, motivating oneself. When performing physical exercise, difficulties, such as lack of motivation, can occur. This can be overcome by exploiting its social aspects of exercise [3]. The designed interactions in this study that consider the social aspects of walking exercise are expected to increase user's motivation. In our system, the user and the avatar cooperate or compete to improve the user's experience and increase their motivation of walking exercise.

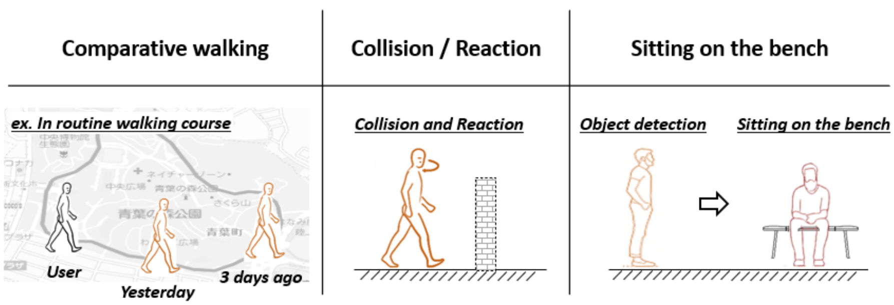

Fig. 5. Cooperative interactions are designed for a user and their AR 3D avatar

Cooperative exercises have been found to increase motivation, prolong exercise, increase positive self-esteem, and even encourage social behaviors with others [6]. A 3D personalized avatar implemented with AR can provide users with the perception that they are doing a specific action, rather than just showing digital information. Through cooperation with an AR 3D avatar, that is, the recognition of walking together, a partner effect can occur during physical activity. The experience of being with someone can increase interest and motivation in users. To make the user aware that they are walking together with a partner, we designed various cooperative interactions. (see **Fig. 5**)

Competition is also an effective way to achieve goals and motivate oneself. It is commonly known that competition has the effect of maximizing human abilities [8]. The scope and form of competition can be diverse; in our system, competition is presented as an intuitive goal and can be performed based on simple rules, during a user's walking exercise. We expect to increase the motivation of a user by encouraging competition with the avatar. To enhance the sense of realism, the emotional expression of the avatar was designed to reflect the competition result. Depending on the competition result, the avatar can express the corresponding emotion through action, such as victory and disappointed.

4.4 System Overview

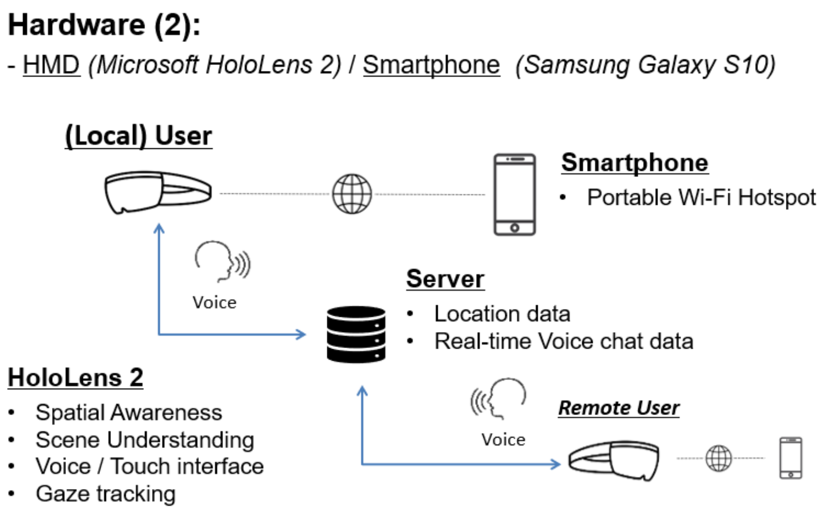

Fig. 6. Overview of the system's structure an components.

Fig. 6 shows the overall structure of our system and its components; we used AR HMD (Microsoft HoloLens 2), and a smartphone (Samsung Galaxy S10) for our hardware devices. An HMD can enable a user to experience VR and AR easily by combining various sensors and input devices and allowing users to experience a fully immersive virtual environment [23]. An HMD enables interaction among the physical world, user, and avatar. We believe that the use of an HMD that can provide a hands-free AR experience is the most appropriate choice for the activity of walking exercise. Hence, the system consisted of minimum hardware, to provide a hands-free walking experience. Since the use of smartphones has become common in physical activity environments in recent years, we also utilized the computing ability of smartphones. We used a server to synchronize the movement of the user and the avatar and to enable the real-time voice chat.

The connection between the HMD and server is made in the state in which the network connection is established. For example, HoloLens 2 supports Wi-

Fi, and so can user the internet to connect to a network. Therefore, we used a server that can be connected to through a device's internet connection. The interaction between local and remote users was through their respective HMDs. Each HMD connects to the network and sends and receives data between the two users through the server under the network connection. In our system, similar to the concept of a multi player game, two players connect to the same room and control their corresponding character. We designed the method of movement synchronization using only the user's HMD, that is, without separate sensors, devices, or equipment.

We used the built-in features of HoloLens 2, such as spatial awareness, scene understanding, voice and touch interface, and gaze tracking. This enabled our system to provide not only visual feedback, but also auditory feedback. We used a smartphone as a portable Wi-Fi hotspot to provide outdoor internet access. The use of the system was divided into the case of one or two users. A single user wears the HoloLens 2 device, and place their 3D personalized avatar in the physical space. The system provides an interface, for example, voice input, eye tracking, and touch interface, and the user starts walking exercise at the desired time and place, with the suggested interactions. In the case of two users, a local and remote user both wear the HoloLens 2 device. Each users' movement is recognized using the camera position of the HoloLens 2, and the corresponding data are transmitted to the server. Meanwhile, real-time location and voice chat data are also transmitted and received through the server.

5 System Implementation

We designed an AR system to provide immersive interaction with a virtual partner while walking exercise, using off-the-shelf devices such as a smartphone and freeware software development kits. This enabled the simple creation of an avatar with the desired appearance, without being overly time-consuming.

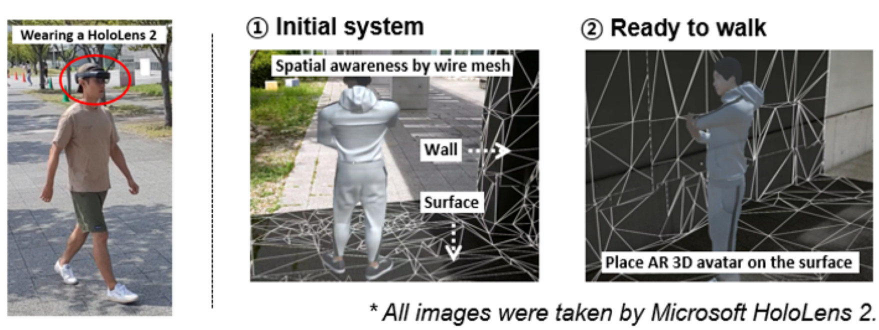

Fig. 7. Demonstration of spatial awareness in our system.

We designed novel interactions for appropriate avatar behavior for the context and situation in walking exercise scenes. Among the many features of the HoloLens 2, our system first utilized the spatial awareness feature. **Fig. 7** shows that this spatial awareness feature provides real-world environmental awareness in mixed reality applications. A user can place their avatar in the physical space and perceive it using the HoloLens 2. Then, the user can walking exercise with the AR 3D avatar. For an immersive walking exercise experience, we designed various interactions with the AR 3D avatar using an interface that the user can intuitively understand; these are outlined in **Fig. 8.**.

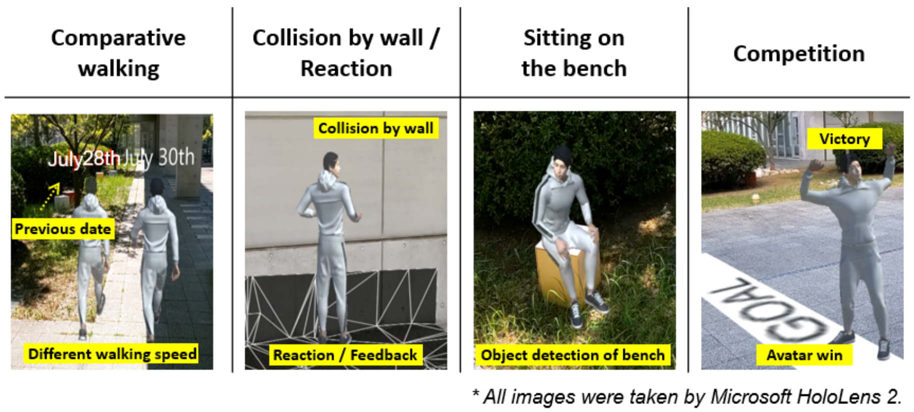

Fig. 8. The proposed system's designed interactions to promote an immersive walking exercise experience.

5.1 Movement Synchronization Between User and Avatar

We designed a novel method to synchronize the movement between the user and the avatar. This method is implemented using the camera position of the HoloLens 2 without separate sensors or equipment, unlike several previous studies, which used a motion capture sensor [24,25]. Thus, both users can experience the mutual presence of each other, through the avatar which the movement is synchronized by remote user, while having hands-free experience. The user's movement state is classified as either idling or walking and is determined by the camera position using the coordinate values of HoloLens 2.

Our system recognizes the change in *"z"* value in the coordinate system of HoloLens 2 as a change in the user's position and implements the corresponding change in the action of the avatar. When the system is initialized, the position of the HoloLens 2 camera, that is, the user's position, has a coordinate value of (0, 0, 0). For example, the current location of the avatar is changed, and is set to (0, 0, 1), so that is differs only in the the *"z"* value, so that the user can see it.

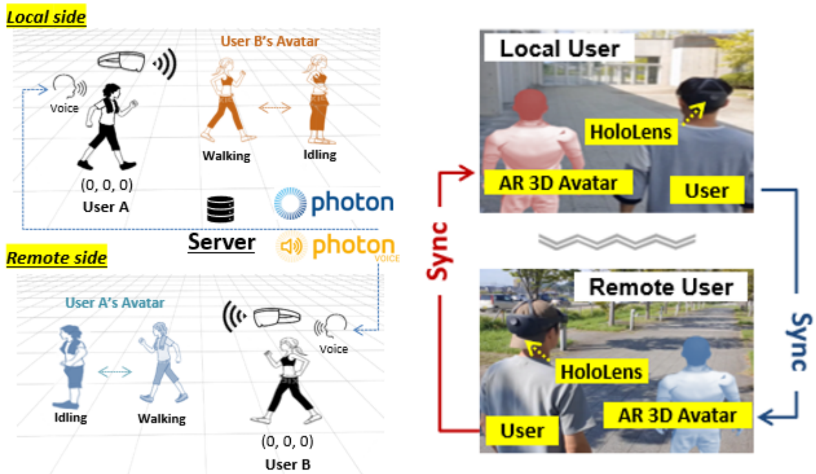

Fig. 9. Movement synchronization method.

For reference, a coordinate value 1 in the HoloLens 2 system represents 1 m in physical space. When the *"z"* value of the remote user changes from the above coordinates, the system determines that the user's walking exercise has started. The movement of the avatar is controlled by the user changing coordinates in the physical space, according to the movement synchronization. To determine the continuous movement of the user, it is necessary to initialize the current position to the previous position every time. Thus, at the code level, an algorithm (see ***Algorithm 1***) determines whether the user is moving by inspecting whether the value of the current position is greater that of the previous position. Specifically, a C# code is implemented to initialize the current position to the previous position in every single frame. Hence, aforementioned, if the current position is greater than the previous position, the action state of the avatar changes to start walking by changing the parameters of the animation controller. Otherwise, the action state is changed to stop walking.

We utilized the concept of a multi player game. First, both local and remote users access the same virtual room. Then, the basic structure of server construction is as follows: (1) create network account, (2) connect network and callbacks, (3) matchmaking: lobby / room, and (4) player synchronization. In our implementation, we built the local and 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 user's avatar. Each 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 is used as a controller to control the movement of the avatar. In this study, we only consider the case of two users. However, we expect to be able to consider the

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

participation of more than two users in the future, depending on the capabilities of the server.

The advantages and disadvantages of the current implementation are as follows. The designed method of movement synchronization uses 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, a hands-free user experience is essential for effective exercise. Thus, our method has the advantage of providing a hands-free user experience and minimizing the restrictions on walking exercise location issues. In addition, since the actual walking motion is applied to the avatar's motion, the most frequent user behavior, a walking motion, can be faithfully expressed in this system. However, 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, a useful extension of this study would be by the implementation of additional synchronization of various actions.

5.2 Direction Control of Avatar by Tracking of User's Gaze

The proposed system uses a method of tracking a user's gaze to control the direction of the avatar. **Fig. 10** shows an editor view, where the yellow line represents the user's gaze. When the user's gaze moves, the avatar follows the yellow line. In this method, HoloLens 2 becomes the controller and controls the direction of the avatar. This is because the recognition of progress direction while walking exercises is most directly and intuitively gained from the user's gaze. The gaze of the user wearing the HoloLens 2 coincides with the direction of the HMD's camera. Thus, the change in the user's gaze coincides with the direction and angle the camera is pointing in. This method is implemented using *Follow* among Mixed Reality Toolkit (MRTK) components, which is a feature in which a digital object tracks the camera position according to the change of the camera.

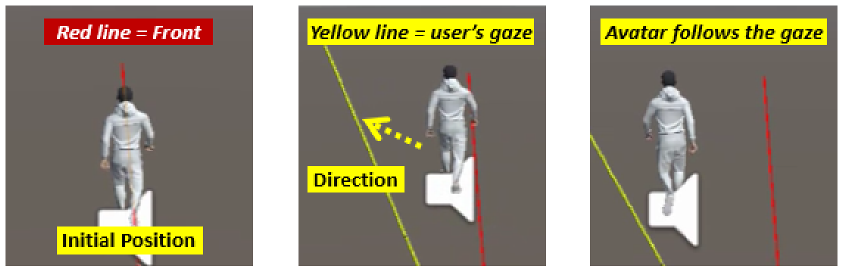

Fig. 10. Tracking of user's gaze for direction control in editor view.

Fig. 11 shows a variety of real examples of our direction control method. We implemented the direction control of the avatar with an interface that users can intuitively understand. The results of these examples confirmed that the avatar moved naturally with the user using this method through the test. We also considered a course identification method using artificial intelligence (A.I.) in the development stage; road segmentation and detection, which are mainly used in autonomous vehicle research, were attempted. During the development process, we succeeded in classifying a road based on a line in the 2D video input. However, we identified a disadvantage in that we were not being able to identify places properly in places where the physical line was not clear. In addition, it was also confirmed that powerful computing is required for a more robust implementation.

Fig. 11. Several test examples of direction control method in a variety of location.

5.3 Interactions for Encouraging the User

Our system can recognize the distance between a user and an avatar; if this reaches a certain distance, without a stop command during the walking exercise, the system determines that the pace of the user's walking is slow, which means the walking exercise motivation is insufficient. Accordingly, the avatar stops the walking action, turns to face the user, and then gives encouragement by clapping; visual and auditory feedback is provided. (see **Fig. 12.**) Then, when the distance between the avatar and the user is restored, the avatar changes action back to the idling state.

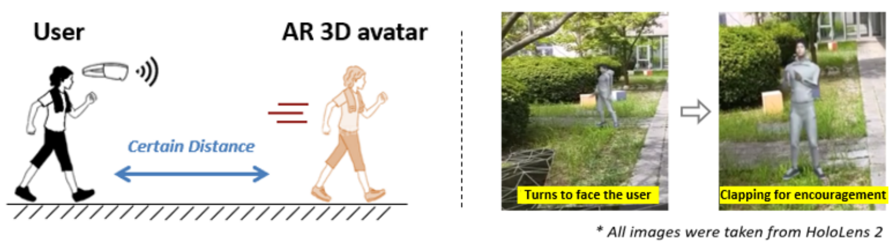

Fig. 12. Clapping action for encouragement.

Our system determines that a user is fatigued based on the duration of the system of use. We designed a high-five interaction between the user and the avatar in order to engage and promote enjoyment in the user. The interaction between the user and avatar is implemented using a touch interface. When a high-five is successfully achieved, visual and auditory feedback is provided. (see **Fig. 13.**)

Fig. 13. High-five interaction between user and avatar.

HoloLens 2's camera has the ability to recognize a user's physical hand, the result of which is displayed with an AR mesh. The touch interface between the user and the digital object (i.e., the avatar and physical hand) uses MRTK's *Near Interaction Touchable* and *Hand Interaction Touch* components. We applied 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, and 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 the *Hand Interaction Touch* component.

6 Preliminary Evaluation

We conducted a preliminary evaluation to evaluate the effectiveness of the proposed system by qualitatively surveying participants regarding their perception and behaviors. A key interest was to obtain feedback from participants. We analyzed the results of the initial user participation and feedback and noted any issues to be addressed in future work.

6.1 Participants and Method

We recruited 8 participants *(6 males, 2 females)* with an age range of 20 to 39: 6 Waseda University graduate students with AR experience and 2 ordinary people with no AR experience. The basic usage of HoloLens 2 was explained before the study for the participants with no AR experience.

The method of preliminary evaluation was a questionnaire, completed by participants after experiencing the system. We conducted the experiment in groups of two people and took about 1 h per group. This timeframe was appropriate for those with previous AR experience, but it was insufficient for those without. We provided a demonstration video (5 min version) to the participants in advance, to give them an approximate understanding of the system. All participants wore a HoloLens 2 and experienced both use cases (walking with an AR 3D avatar or walking with a remote partner) in outdoor setting. We observed and recorded the participants' behaviors and comments during the user study. After the questionnaire was completed, a brief interview was conducted with the participants, and the results of both the questionnaire and short interview were analyzed. Since this preliminary evaluation was a qualitative evaluation, specific measurements of usage time and walking distance were not conducted. This evaluation method aimed to identify the understanding, experience, and interest of the participants in the overall system.

6.2 Results

In this section, we present the analysis of the results from the preliminary evaluation of the proposed system. We analyzed five areas based on the result of the questionnaire and short interviews, and observation of participants behavior:

(1) usability, *(2) sense of presence*, *(3) novelty*, *(4) effectiveness*, and *(5) continued use of system*. **Fig. 14** outlines these results. We can see that most of the participants responded positively in the questionnaire, suggesting that designed interactions with a virtual walking partner can increase a person's motivation or walking exercise. All the results in this preliminary evaluation are qualitative, thus a quantitative evaluation will be conducted in the future.

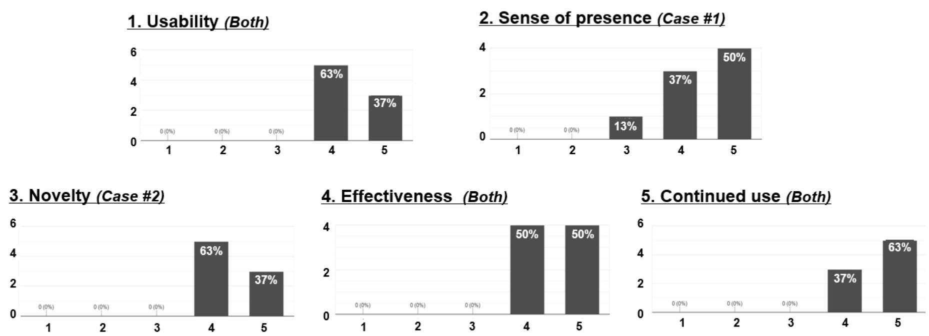

Fig. 14. Results of the participant questionnaire.

6.3 Discussion

From the results of the preliminary evaluation, we expect that our system will increase the motivation of walking exercise. However, we also found several issues and limitations in this initial stage of the system. The followings are the discussion issues:

1. **HoloLens 2 for walking exercise**: We believe wearing an HMD should be similar to wearing sports goggles, with minimal inconvenience. To investigate this, we compared the weights of various devices. The weight of HoloLens 2 has a significant disadvantage, with an average weight of 556 g, compared to sports goggles, with an average weight of 35g. However, safety helmets used on construction sites weigh 300 g on average; hence, we can infer that the HoloLens 2 can be worn for long periods of time. Finally, since the target of this study is walking exercise, which differs from running, we believe that HoloLens 2 will not limit.
2. **Unexpected movement of avatar**: We utilized the spatial awareness of HoloLens 2 to place the avatar in the physical space in our system. However, a time delay between the display of the avatar and the space calculation occurs due to the computational limitations of HoloLens 2. Additionally, our system used the coordinate system of the HoloLens 2 camera to synchronize

the movement of the avatar and the user. The proposed method uses only the *"z"* value of the 3D coordinate system; thus, when the user's *"x"* and *"y"* axes are changed, it is necessary to calibrate the *"z"* value required for the movement of the avatar. However, because the calibration value is not applied at this stage, so unexpected movement appears.

3. **Restricted interaction with avatar**: We found that the interaction between the user and the avatar is relatively one-sided. The interactions implemented in this prototype system only allow the user to interact with the avatar through the situation and interface specified in advance during the development process. Thus, depending on the situation, the user may feel that their virtual partner is acting out of context. To address this, complicated real-time calculations are required, which is challenging for the limited computational power of the HoloLens 2. Therefore, it is necessary to consider a combination of devices and technologies to improve the system.

7 Conclusion

We designed an AR system to increase the motivation of walking exercise. Specifically, a 3D personalized avatar was implemented as a virtual partner in AR. We designed a novel interaction that enables a user to experience a realistic walking experience with a virtual partner for two different use cases. In Case #1, we designed interactions between a user and an avatar. In Case #2, we designed a novel method of movement synchronization between user and the avatar, using only the HMD without additional sensors, to enable a user to walk together with a remote user via their respective avatars.

We investigated the effect of our system with a qualitative preliminary evaluation. The results of the questionnaire outlined a positive response from most of the participants. These results support the idea that novel interactions in walking exercise scenes between a user and an avatar, while walking, can increase the motivation of walking exercise. In addition, some participants showed an interest in the system, demonstrating the potential of the proposed system to make a repetitive physical world walking exercise more entertaining. In the future, we plan to investigate a quantitative evaluation [27] by, for example, comparing the duration and distance of a user's walking exercise with or without our system. We believe that the above two factors are important to confirm and quantify the increase in a user's motivation.

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