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# An Asymmetric Multiplayer Augmented Reality Game with Spatial Sharing of a Physical Environment

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**Abstract**

*In this paper, we propose a competitive game in which a player wearing an augmented reality (AR) head-mounted display (HMD) and a player not wearing an HMD share not only a virtual environment but also the structure of a physical environment. Through the proposed game, we explore the interaction between players in an online multiplayer game using an AR HMD, which is enjoyable and has a high social presence. For this exploration, we created a game design that actively utilizes a physical environment and the asymmetry between players wearing and not wearing an HMD. We implemented the designed game and conducted a user study (n=14) to evaluate the game using the Game Experience Questionnaire and an our own questionnaire. The results revealed that the players had a highly positive affect toward the game and showed a high social presence. We also obtained insights into how to make the game more interesting and to increase social presence of players.*

**CCS Concepts**

• ***Human-centered computing*** → ***Interaction design theory, concepts and paradigms;***

## 1. Introduction

In recent years, virtual reality (VR) and augmented reality (AR) technologies have made significant progress. In particular, VR and AR using a head-mounted display (HMD) can provide users with a highly immersive experience, and products such as Meta Quest are already in widespread use.

One field of research using HMDs is remote work support through remote collaboration. In studies of this field, a local user's surrounding environment is shared with a remote user, enabling the remote user to understand the local user's environment accurately and to give detailed instructions [TLL*19, BSYB20, OES*15]. It has been shown that social presence in remote collaboration is enhanced by sharing a local user's eye gaze and gestures in addition to verbal communication [BSYB20]. Asymmetric interactions in which HMD users and non-HMD users share the same virtual space have also been studied [WACKdA*21, JWL*23].

Interaction with physical environments has also been the subject of much research. Some of studies in this field have increased the immersion and enjoyment of an HMD user by allowing an HMD user to physically walk around and experience interactions with haptic feedback [SGJM18, COHW19, CRR*15, XST*18]. Co-located multiplayer games have been found to be highly valued by players, and physical environment-based co-located multiplayer games using HMDs [GSFR17] have been proposed. However, few studies have explored online multiplayer games using AR HMDs.

We propose an online multiplayer game in which a player wearing an AR HMD and a player not wearing an AR HMD share a structure of a physical environment. The structure of the environment around the HMD player is virtually reproduced in the virtual environment of the other player, and virtual objects such as enemies are placed based on the physical environment and presented to both players.

Asymmetric gameplay by HMD and non-HMD players in a shared physical environment, has been found to be preferred by players [GSFR17]. Therefore, the game system is designed to share a physical environment where one HMD player is located with a remote player not wearing an HMD. By creating a game system that actively utilizes a physical environment and asymmetry between players wearing and not wearing an HMD, we aim to provide players with a high enjoyment and social presence.

## 2. An Asymmetric Multiplayer Augmented Reality Game

### 2.1. Using the asymmetry between players

Regarding asymmetric gameplay wearing and not wearing HMDs, a previous study has revealed that players tend to prefer different perspectives, different power levels, and different interaction methods in a same virtual environment [GSFR17]. Therefore, the proposed multiplayer augmented reality game is played in an asymmetric setup by a player with an HMD and a player without an HMD.

As shown in Figure 1, an HMD player has a first-person perspective, and the remote player is free to view the environment around



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the HMD player. In addition, to make the interaction method asymmetric among players, we designed a shooting game for an HMD player and a real-time strategy game for a remote player. In the shooting game, an HMD player aims to survive by avoiding enemy attacks placed in physical environment and firing bullets to defeat enemies. In the real-time strategy game, a remote player aims to defeat an HMD player by placing characters that are enemies of an HMD player. The game is a battle between an HMD player and a remote player. An HMD player views the physical environment from a first-person perspective, while a remote player views a display that shows a structure of a physical environment in which the HMD player is located, as well as the HMD player's position and direction in real time. A remote player checks an HMD player's position and direction and places characters in the shared environment to attack an HMD player. A remote player can also change the position and direction of the perspective to have a bird's eye view, for example. When a remote player places a character on the shared environment, the character simultaneously appears as an enemy in the HMD player's screen, and the HMD player can avoid enemy attacks through physical movement or attack enemies.

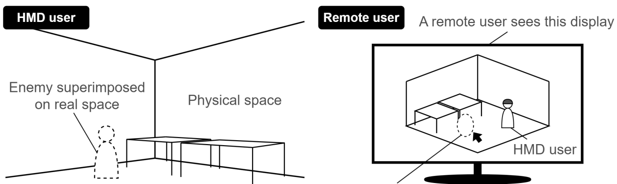
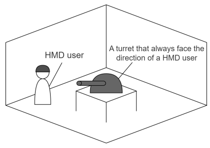
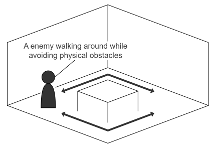


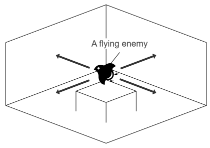

**Figure 1:** *Design of game screens for each player.*




**(a)** *A turret fixed on a surface.*




**(b)** *A walking character.*




**(c)** *A flying character.*

**Figure 2:** *Three types of characters whose actions are limited by obstacles in a physical environment.*

### 2.2. Use of a physical environment

In the proposed game, an indoor environment with a certain size and obstacles is assumed, and three types of characters are designed whose actions are further limited by physical environments and obstacles. This is a scheme that enhances a strategic nature of the game and makes the game more interesting for players. The character designs are shown in Figure 2. Figure 2 (a) shows a turret fixed on a flat surface in a physical environment, such as a wall or a desk top. When a turret is in a position where an HMD player can see it, it fires shots at the HMD player at regular intervals. Figure 2 (b) shows a character that can walk on the floor and moves to follow an HMD player. However, the character bypasses obstacles on the floor such as desks. Figure 2 (c) shows a character that can fly in the air and moves to follow an HMD player. This character can move without being restricted by obstacles on the floor such as desks. Neither of the characters moves without regard to physical objects, such as sliding through walls or desks.

### 2.3. Game Design

An HMD player can shoot bullets by using gestures. The bullets go straight in the direction an HMD player is facing, and when they hit an enemy, the enemy disappears. When an HMD player's bullet collides with a turret's bullet, both bullets disappear.

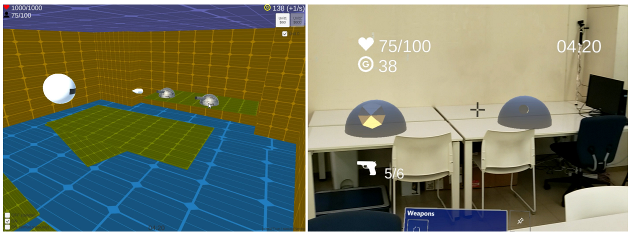
A remote player can place a character by clicking on a flat surface such as a wall, floor, or ceiling. The position and direction of an HMD player can also be checked in real time, allowing a player to place a character behind or under the HMD player's feet. It takes approximately two seconds from the time of the click until the character is actually placed. During this time, a sound and a visual effect is emitted from the position where the character will be placed to give an HMD player a warning in advance. A limit on the number of simultaneous character placements is set, which is appropriate for a size of a physical environment in which the game is played. Character placement also incurs a cost, and the cost of possession increases over time. A turret always attacks an HMD player, but the attack is interrupted when there is an obstacle between the turret and the HMD player.

To make an HMD player more aggressive in defeating enemies and a remote player more efficient in attacking an HMD player, we introduced a score system: an HMD player's score increases when defeating enemies and a remote player's score increases when attacking an HMD player. An HMD player has an HP, which decreases as the player is attacked by enemies. A remote player wins when HP reaches 0, and an HMD player wins when 90 seconds elapses while still having HP.

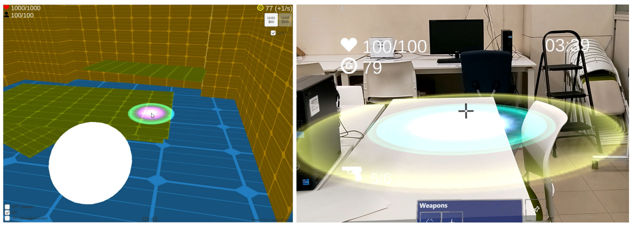
## 3. Implementation

We implemented a prototype game based on the proposed game design. The AR HMD is a Microsoft HoloLens2, an optical see-through head-mounted display. The application was implemented using Unity and the Mixed Reality Toolkit, which is a HoloLens2 application development tool for Unity. Microsoft's Scene Understanding was used for recognition of a physical environment. This tool estimates structure of an indoor environment, such as walls, floors, and desks, based on mesh data of the surrounding environment acquired by HoloLens2 using spatial mapping, and provides a 3D representation similar to the one used in Unity. Photon Unity Networking2 was used for communication between applications, such as spatial sharing of a physical environment.

Figure 3 (a) shows the game screen for each player. This shows a turret and an HMD player facing each other. The left side of Figure 3 (a) is a remote player's screen; the HMD player's position and direction is represented by a white sphere, and the structure of a physical environment is represented by colored planes arranged around the white sphere. Figure 3 (b) shows the visual effects that occur when placing the characters. A sound that accompanies the visual effects allows an HMD player to recognize the presence of enemies before they actually appear. However, it is not possible to confirm which type of enemy will appear.




**(a)** *On the left is a remote player's screen and on the right is an HMD player's screen.*



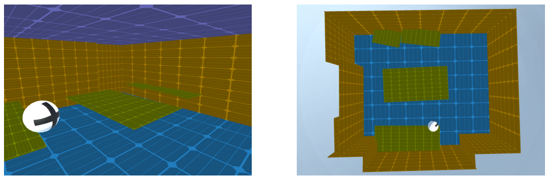

**(b)** *When a remote player clicks on the screen, the visual effect occurs on both players' screens.*

**Figure 3:** *Screenshots of gameplay.*

## 4. User Study

We conducted a user study to explore the interaction of the proposed game and to measure the emotions, immersion, and social presence it provides to players. The core and social presence modules of the Game Experience Questionnaire (GEQ) [IdP13] were used for evaluation. In addition, we used our own questionnaire with an open-ended question to evaluate the effectiveness of the proposed methods. The our own questionnaire included three items: whether the use of the structure of the physical environment enhanced the strategy of the game (Q1), whether sharing the structure of the physical environment made the game more interesting (Q2), and whether the different ways of playing between an HMD player and a remote player made the game more interesting (Q3). Both items were evaluated on a 5-point Likert scale (1: Not at all - 5: A lot).

We also created two game modes for a remote player, one in which a player can freely move his/her perspective (Perspective) and the other in which a player can view a physical environment from a bird's-eye view without moving his/her perspective (Bird's-eye). We then investigated the effects of these differences on the game. This was conducted using repeated measures ANOVA with a remote player's two game modes (Perspective, Bird's-eye) and device (HMD, Remote) as independent variables. The game screens of a remote player in each mode are shown in Figure 4.



**(a)** *In perspective mode, perspective can be moved freely.* **(b)** *In bird's-eye mode, perspective is fixed at a bird's eye view.*

**Figure 4:** *Difference between the two perspectives.*

### 4.1. Participants

Fourteen participants (5 females and 9 males) with an average age of 22.79 (SD=1.47) participated in the study. Participants were recruited in pairs from students outside our lab.

### 4.2. Procedure

A rectangular room with desks in the center of the room and along the walls was prepared, and participants were invited in pairs. The experimenter explained the procedure of the study and the rules of the game to the participants. Then, the participants practiced the game on the HMD and the computer. After the practice, the participants played all four game plays of our independent variables (Game mode $\times$ Device). The participants performed each game play for a fixed duration of 120 seconds. After each game play, participants answered the GEQ. After all game plays were completed, participants answered an our own questionnaire. At the end of the study, participants received a small honorarium.

All participants played alternately on an HMD player's side and remote player's side. The order of the game modes was counterbalanced. If one pair played the perspective mode first, the next pair played the bird's-eye mode first, and vice versa.

### 4.3. Results

The core module of the GEQ assesses the gaming experience with seven items: immersion, flow, competence, positive and negative affect, tension, and challenge. The social presence module of the GEQ examines psychological or behavioral involvement with other players. Psychological involvement consists of two items, empathy and negative feelings, and behavioral involvement consists of one item. Since the scores were not normally distributed, a 2x2 (Game mode $\times$ Device) within-subject two-way ANOVA was conducted after applying a nonparametric Aligned Rank Transform.

The mean values for each item are shown in Figure 5. HMD players reported significantly higher flows than remote players ($F(1, 26)=4.302$, $p=0.043$). No significant differences were found for the other items for either game mode or device. However, the overall positive affect was high and the negative affect was low, indicating that the participants had a favorable impression of the game. HMD and remote players enjoyed the game to the same extent because there were no significant differences between both players in these two items. One of the participants stated, "*Experiencing both the HMD and the remote made the second game play more enjoyable*" (P6).

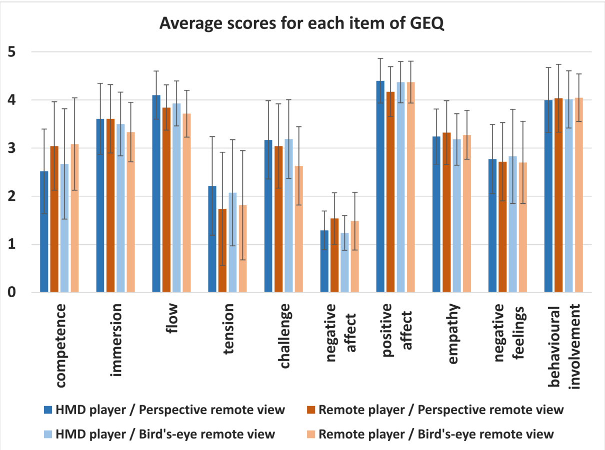



**Figure 5:** *Average scores for each item of GEQ. Error bars indicate standard deviations.*

In competence, the value of the *HMD* was slightly lower than that of the *Remote*. Several participants stated that they had never used the HMD before and could not get used to its operation (P6, P12). Some participants also pointed out that the narrow screen of the HMD led to difficulty in playing the game. It is clear that becoming accustomed to the HMD will lead to improved game play, but it is also necessary to devise ways of dealing with the limitations of the HMD's image rendering range. For example, an indicator that shows a position of enemies out of view or hints on how to operate the HMD or how to play the game should be displayed during game play. One comment indicated that a remote player's main operation was only to position the character, but this was perceived positively. "*It was very easy and fun because all I had to do was place my character while thinking about the opponent's position and direction*" (P12).

In terms of social presence, empathy exceeded 3 and behavioral engagement exceeded 4 for all game plays. Although the proposed game seems to provide a high social presence overall, there were some comments that called for more connection between an HMD and remote player. One participant commented, "*I felt that there should be more elements that allow an HMD player and a remote player to feel more connected*" (P14). Since an HMD player and a remote player play against each other via virtual characters, creating a game system that allows players to feel more directly connected to their opponents is expected to further improve scores. It would also be effective to create a game system in which players cooperate with each other to complete the game, rather than playing against each other.

The results of our own questionnaire are shown in Figure 6. Most of the scores were 4 or 5, which was highly evaluated. In particular, Q3 had a very high percentage of 5 (11 out of 14), confirming that asymmetric gameplay was preferred by the participants. Q2 had a high overall score, but the percentage of 5 was lower than the other two questions, with one participant answering 2. Many participants found the physical environment-based game experience interesting, but one participant commented that "*the HMD side of the game is often played on the same stage*" (P5). Regarding Q1, we observed that participants were actively experimenting with various strategies, such as focusing on continuously avoiding enemy attacks or using moving characters to sway an HMD player's gaze. By increasing a number of character types and interaction methods of an HMD player, we expect that players will be able to experience a more strategic game experience.

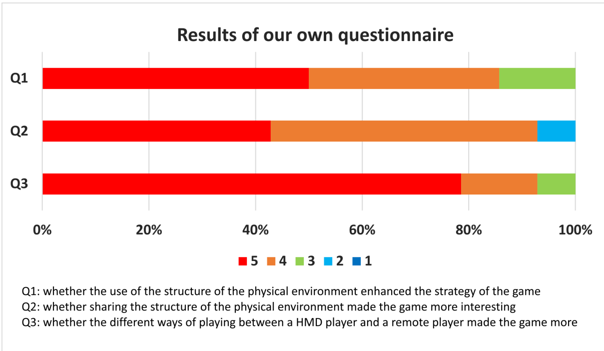



**Figure 6:** *Results of our own questionnaire. The median score for each question was Q1: 4.5, Q2: 4, Q3: 5.*

## 5. Conclusion

In this paper, we proposed an asymmetric multiplayer augmented reality game, a competitive game using an AR HMD. To take advantage of the virtual experience using the HMD, the game is played with spatial sharing of a physical environment among multiple players. We created a game experience that players can enjoy by creating a game system that actively utilizes a physical environment and asymmetry between players wearing and not wearing an HMD.

A user study (n=14) was conducted to evaluate the emotions, immersion, and social presence of the proposed game on the players. The results of the study showed that players exhibited highly positive affect and social presence toward the game. This indicates that the game system proposed in this study is one effective interaction method for online multiplayer games using HMDs. The asymmetric game design and in-game characters that move in accordance with the physical environment proposed in this study are expected to generate positive emotions among users in other virtual experiences using physical environment.

This game was designed for a pre-assumed indoor environment, and the characters were designed with specifications that match the environment, such as character's movement speed and the number of simultaneous placements possible. In order to play the game in various physical environment, it is necessary to design and evaluate a function that adjusts character specifications and game rules according to the size of the physical environment and the amount of obstacles.

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