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Understanding Privacy Awareness in Immersive Spatial Sharing System

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With the advancement of point cloud collection technology and high-performance computing, immersive remote spatial sharing systems that enhance caregiving and family interaction are highly anticipated. In particular, advanced spatial sharing systems are being developed to scan and merge each other's spaces into a virtual environment. However, this new form of interaction may raise privacy concerns distinct from those associated with traditional telephone or video conferencing. In this study, we investigated the privacy concerns arising from highly immersive spatial sharing systems. We developed a spatial sharing system consisting of multiple depth cameras and servers designed for use in two or more remote locations. Each location's surrounding environments and objects are captured and represented as point clouds, then mapped into a shared virtual space. Thirty-nine participants attended an experience session on the spatial sharing system and responded to a questionnaire. The survey collected information on privacy awareness during the use of the spatial sharing system, the quality of the system's equipment and interactions, and some basic user attributes. Additionally, it inquired how users' awareness changes when some parts of the space related to subjective privacy are modified. Furthermore, data was segmented into clusters based on age group and gender, and statistical tests were conducted between two groups within each cluster. The results showed several statistically significant differences, including differences in privacy awareness and the usefulness of the proposed spatial sharing system.

1. Introduction

Spatial sharing systems that merge multiple spaces from remote locations can be utilized for purposes such as elderly monitoring and remote education, enabling highly immersive interactions. An example of such systems is the Cyber-Physical Spatial Sharing System (hereafter referred to as the spatial sharing system).[(1)] Although these systems allow for more immersive interactions than traditional telephone and video conferencing tools, they may also

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introduce new privacy issues. Research on privacy awareness or policies is conducted and handled in various ways in many fields.[2] In this study, we treat privacy awareness as the subjective feeling of whether the user wants to hide particular objects. Although studies address subjective privacy similar to this research, most focus on web conferencing using PCs or chat-based communication on social networks. Therefore, there is a need for research on subjective privacy in the context of spatial sharing systems.

In this study, we aim to clarify users' subjective privacy concerns when utilizing the spatial sharing system. Ultimately, the goal is to develop a system to keep immersive spatial sharing while filtering out objects based on users' feelings and attributes. A previous study[3] has collected and analyzed many privacy requirement data during remote cooking class with spatial sharing through crowdsourcing. However, owing to implementation limitations, it was not possible to obtain survey responses based on actual experiences, and participants could only answer by imagining interaction scenarios. Another previous study[4] identified specific trends between user attributes and privacy awareness using a spatial sharing system. However, the number of questionnaire responses about user attributes was insufficient for statistical evaluation. Therefore, we extend the previous study[4] by collecting more user responses and evaluating the system through statistical tests.

To collect the amount of data for the evaluation, we developed a prototype system and held a trial session. The system has functions to share each user's physical spaces and hide private objects as a privacy filtering feature. During the session, participants experienced the spatial sharing system's operation and demonstrated the privacy filtering feature. Participants also provided basic information such as age, gender, and familiarity with information technology. After the trial, they answered questions regarding the system's video and equipment, the quality of the experience, privacy awareness, and the privacy filtering feature. The experience session was conducted twice, and 39 general participants provided questionnaire responses. The analysis of the questionnaire results using the Mann–Whitney U test revealed differences in privacy awareness based on gender or age group. For instance, in the case of the gender group, significant differences were observed in several items, such as "Anxious About Sharing My Space with Others" and "More Privacy Concerns than Using Phone for Communication". This study extends the previous research[4] with additional experiments and statistical analysis to objectively evaluate and discuss the questionnaire results. The findings of this study suggest subjective privacy requirements in new communication systems such as remote spatial sharing systems.

2. Related Research

Privacy consists of various elements, including the desire to prevent others from seeing certain things and the concern about whether an individual can be identified from the provided data. In this section, we first explain the type of privacy addressed in this study on the basis of the relationship between security and privacy. Then, we highlight the challenges of traditional digital communication tools. Next, we discuss previous research on privacy in cyber-physical spatial sharing systems. Finally, we describe the position of this study within the existing research.

2.1 Subjective privacy in virtual environment

In the context of privacy protection, security elements are often discussed. De Guzman *et al.*[5] defined security-oriented and privacy-oriented elements as privacy components in three-dimensional (3D) spaces, presenting Properties, Threats, and Models. According to their paper, the relationship between security and privacy can be derived from three models and comprehensively explained. Microsoft's Security Development Lifecycle[6] primarily focuses on security, emphasizing properties such as authentication. The PriS method[7] centers on intermediate properties between security and privacy, such as identification and confidentiality. Deng *et al.*'s proposed model[8] mainly focuses on privacy, emphasizing properties such as unobservability and undetectability.

Privacy issues in conventional metaverse environments are primarily based on the elements above, which are more abstract and relatively higher-level concepts.[9,10] In contrast, the privacy addressed in this study is more specific, quantifying what information users feel comfortable being seen or prefer to keep hidden. In this context, a specialized privacy filtering technology is needed to determine whether to show all objects in the space to others, replace them with virtual representations, or hide them entirely.

2.2 Research on privacy in remote communication

Discussions regarding privacy requirements in remote communication have long been conducted in contexts such as video conferencing[11] and social networking services,[12] not limited to the spatial sharing systems addressed in this research. Particularly for two-dimensional (2D) images, many studies employ processing techniques[13] classified into nine categories to protect privacy within images: "Intervention", "Blind Vision", "Secure Processing", "Redaction: Image Filter", "Redaction: Encryption", "Redaction: K-same Family", "Redaction: Object/People Removal", "Redaction: Visual Abstraction", and "Data Hiding". These techniques aim to determine whether objects appearing in the images affect privacy and modify the images to blur or replace the target objects with abstract representations, balancing privacy protection with realism. Additionally, the research field includes de-identification, which involves more complex processing using technologies such as machine learning rather than simple methods such as Gaussian blur.[14] These studies are significant in examining basic human privacy needs and methods to fulfill those needs. These discussions are based on interactions through 2D media or non-real-time exchanges. However, they have not explored privacy requirements sufficiently in 3D spatial sharing systems where every object in a user's space might be scanned and shared.

Studies on privacy awareness in 3D images are also conducted. For example, some studies aim to clarify privacy awareness when using VR technology.[10] The results suggest that the presence of others in a social VR space can affect the sense of privacy.[15] Additionally, there are surveys on both the privacy and security aspects of VR technology.[16] These studies mention individual differences in privacy awareness among users active in virtual spaces, which is useful for achieving the privacy filtering technologies this study aims for. However, more applicationoriented investigations into the specific contexts of daily life and what type of privacy awareness users may have in different situations have not been conducted.

In addition, some studies discuss privacy issues specific to interactions in shared virtual spaces. Giaretta[(17)] highlights concerns that the physical and psychological data collected by VR goggles and other devices may pose privacy risks to users. This suggests that VR devices can capture more characteristics than traditional communication tools, enabling the identification of participants and the estimation of environmental information behind them. Dick[(18)] discuss how data observable by others, such as virtual avatars and surrounding environments, are essential for enhancing the immersive experience of VR/AR. This also addresses the privacy concerns associated with such data, emphasizing the need for users to be able to choose, in a transparent manner, when and how their data is observed to mitigate privacy risks. In another study, O'Haga *et al.*[(19)] focus on the privacy of bystanders whom AR technologies may capture. The survey results suggest that bystanders may find it challenging to recognize and fully understand the data collected around them.

These studies suggest that data collection in 3D environments may raise more complex privacy issues than in 2D environments. In particular, the 3D reproduction of environments, including individuals, contains more information than 2D representations, necessitating more complicated privacy protection measures.

2.3 Privacy in cyber-physical spatial sharing systems

Spatial sharing systems combining multiple spaces in remote locations can be utilized to monitor the elderly and remote education, enabling highly immersive interactions.[(20)] A spatial sharing system has been proposed as an example of such a system. Although these systems allow for more immersive interactions than do traditional phone or video conferencing tools, they also have the potential to introduce new privacy issues.

Our previous research[(1)] has considered that privacy requirements are determined by the context related to the shared objects, current actions, the surrounding environment, relationships with others, and the user's personality traits. The following function *pl* defines these requirements:

$$pl: C \times O \times P \rightarrow L, \tag{1}$$

where C represents a set of contexts, O represents a set of objects, P represents user personality traits, and L represents privacy protection levels. On the basis of the above definitions, we conducted a data collection experiment asking about privacy requirements for various objects appearing in images. We also collected the BIG5 personality traits, a representative measure for modeling human personality. Participants were recruited via a crowdsourcing website. After watching an image simulation of remote interaction systems, they responded to privacy requirements for each object shown. Responses were obtained from 300 general participants for each of the three behavioral contexts. As a result, we could classify objects into three categories, namely, acceptable to be seen, indifferent, and not acceptable to be seen, with an accuracy of approximately 64% using machine learning technology.

However, since participants did not experience the actual system in the previous research,[3] their responses were based on imagination. Furthermore, significant individual differences in privacy requirements were observed, revealing that sufficient accuracy cannot be achieved without tuning the model for individuals.

2.4 Position of this research

Experiments involving actual system use are necessary to collect more realistic data on privacy requirements. Moreover, to improve accuracy, it is essential to consider parameters that may relate to users' understanding and immersion in the system, such as age, gender, and familiarity with information technology, in addition to personality traits.

Therefore, in this paper, we describe the result of the general public experience of a spatial sharing system in a workshop format. Participants will interact with remote individuals through the system's implemented privacy filtering technology and answer questions about their interactions and privacy awareness. By statistically analyzing these responses, we aim to quantitatively examine the privacy requirements for spatial sharing systems.

3. Spatial Sharing System

In this section, we describe the spatial sharing system that we developed, the system interface, and the object filtering function. Figure 1 shows an overview of the spatial sharing system. This system provides immersive spatial sharing and privacy protection mechanisms that can set objects' display and non-display.

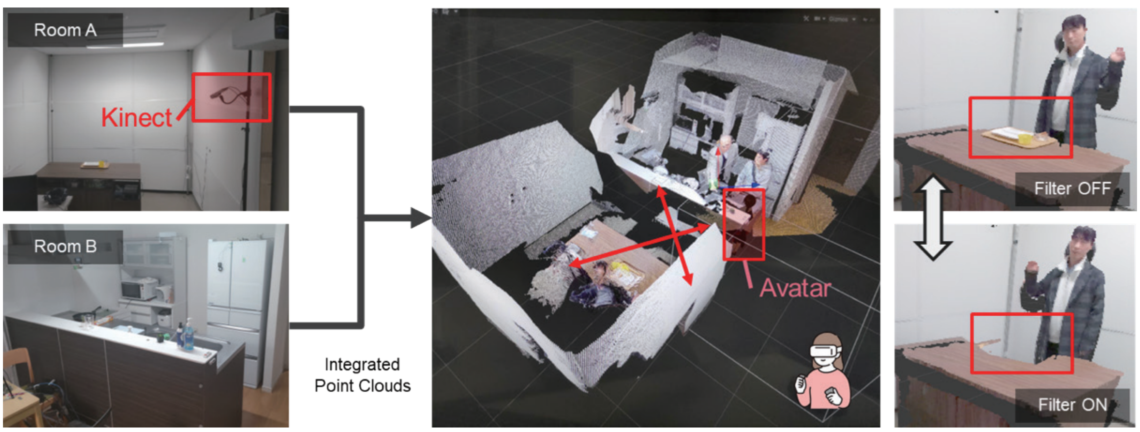


Fig. 1. (Color online) Overview of proposed method. Point clouds captured by Kinects in remote rooms A and B are integrated and reconstructed in a virtual 3D space. Using a VR HMD, users can access this space, enabling them to enter the other user's space through an avatar or filter objects to ensure privacy protection.

3.1 Integration of multiple cyber-physical spaces

We previously attempted to integrate spaces by projecting the other party's space onto a wall using a projector. However, this method had issues such as low immersion, the high cost of multiple cameras and projectors, and occlusion during projection. Therefore, we utilized VR technology to recreate the desired shared space in a virtual environment based on the point cloud information of the actual space. By communicating through a virtual reality head mounted display (VR HMD), users can interact as if they were next to each other and easily perform operations such as displaying objects with privacy concerns.

To recreate a space in the virtual environment, measuring the relative coordinates and shapes of objects in the real space is necessary. After that, the information needs to digitize and reconstruct them in 3D. In this method, a light detection and ranging (LiDAR) sensor and an image sensor are used to obtain the coordinates and color information of objects as spatial data, and the space is reproduced by rendering a vast number of points on the VR HMD. The recreated spaces can be expressed as integrated by adjusting and rendering their positions in the virtual environment. Users can freely move within this integrated space and virtually enter the recreated space of the other party.

Object occlusion in complex environments with numerous objects makes it difficult to obtain spatial information behind each object. To mitigate the reduction in immersion caused by this phenomenon, multiple LiDARs are installed to cover sightless spots. However, increasing the number of LiDARs leads to a greater volume of point clouds, resulting in higher demands for communication bandwidth and computational resources. Therefore, considering the available rendering resources and communication speed, we arranged to place two LiDARs per room. Additionally, since point density decreases with distance from the LiDAR, we installed the LiDARs from the front to the center of the room rather than along its diagonal.

3.2 User interface on the spatial sharing system

Nonverbal information, such as the sense of physical distance, is essential for more intimate communication in addition to voice. To express such information and enhance immersion, we designed an interface in the spatial sharing system that allows free access to each other's spaces. When using VR HMDs, self-positioning technology such as simultaneous localization and mapping (SLAM) allows users to move around. However, when watching virtual reality videos of real spaces, there is a risk of bumping into furniture, walls, or other people. Therefore, this interface adopts a method of moving the viewpoint in the virtual space using the controller that comes with the VR HMD. Users can enter the other person's space without moving, enabling communication as if they were right next to each other despite being far apart.

Additionally, since the user does not move while virtually traveling, their point cloud representation also does not move. In such cases, they cannot convey their approach to the other person in the virtual space. To address this, we placed an avatar synchronized with the user's viewpoint position in the virtual space, allowing the user to communicate their position and posture to the other person, as shown in the central part of Fig. 1.

When using the spatial sharing system, it is necessary for users to be able to select in real time what they want and do not want to show. Therefore, a privacy filtering function is needed to hide automatically the objects that users do not wish to show without requiring them to select every object. In a previous study,(3) a machine learning model was constructed to estimate the privacy requirement information for each object and each user in the context of a remote cooking class. However, owing to the difficulty in constructing personalized models for evaluation experiments, a prototype interface was created to experience privacy filtering. This prototype allows users to switch the display of preset objects. The appearance is switched by pressing buttons on a controller corresponding to the objects, enabling them to control the display of specific objects.

4. Experiment

To clarify how a spatial sharing system utilizing privacy filtering generates privacy awareness compared with traditional communication, we held a demonstration experiment of the spatial sharing system. This system was experienced by general participants recruited through a public call. Figure 2 shows an overview of the architecture of the demonstrated system.

4.1 System setting

The experiment was designed as an online family communication during cooking, with two physically separated rooms, A and B, integrated into a virtual space. The system consists of LiDARs for point cloud acquisition, a point cloud distribution server, a point cloud rendering server, and VR HMDs.

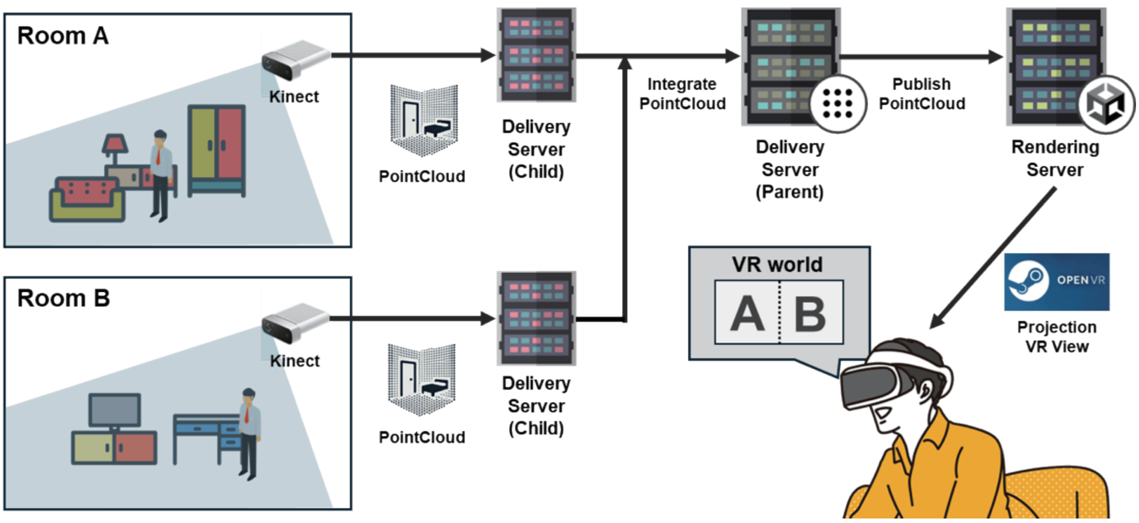


Fig. 2. (Color online) Overview of architecture of spatial sharing system.

We employed Microsoft Azure Kinect, the LiDAR for spatial information measurement, with two units in each room. Point cloud distribution servers collected these sensor data in each room, and spatial information was distributed to the point cloud rendering server via the Robot Operating System (ROS). Unity software on the point cloud rendering server reconstructed the distributed spatial information in 3D. After that, the point cloud was rendered on the VR HMD display using Valve's OpenVR SDK. HTC's Vive Pro 2 was adopted as the VR HMD. The Vive Pro 2 precisely tracked the wearer's movement by placing tracker sensors in the room, providing higher immersion in the virtual space. High-performance GPUs are required to render hundreds of thousands of point clouds rapidly. An RTX 4090 graphic card was used in the point cloud rendering server for the system. Additionally, all communication channels were built on a 10 Gbps Ethernet base. This experiment was conducted with the approval of the Ethics Review Committee of Nara Institute of Science and Technology (Review Number: 2019-I-9-2).

4.2 Experimental conditions

The experiment was designed as follows. First, participants were informed of the purpose of the experiment and an explanation of VR. Next, they were divided into two groups, half in room A and half in room B. The people in room A wore VR HMDs, used controllers to navigate within the spatial sharing system, and communicated remotely with people in room B, thus experiencing remote communication through the spatial sharing system. Following this, they experienced switching the display and non-display of privacy-sensitive objects. Once all participants in room A have completed their experience, the groups from rooms A and B switched places and repeated the same procedure. Finally, the participants were instructed to complete a questionnaire to investigate their user experience and privacy concerns. Figure 3 shows the scene of the actual experiment.

VR usage was restricted for participants under the age of seven on the basis of guidelines(21) suggesting that it is not advisable to use VR during the development of stereoscopic vision. Instead, a pseudo-virtual environment was created by projecting the VR HMD display onto two wide monitors to cover the field of view adequately, and the experiment was conducted with the participants below the age of seven observing this immersive view. Children aged seven to below thirteen years participated in an interaction experience using VR goggles, with parental consent. Similarly, all participants aged thirteen and above also engaged in the interaction using VR goggles.

5. Results and Discussion

The evaluation experiment was conducted over two days. Participants were ordinary citizens recruited through the website, direct mail, and other means. At least one member from each group completed the post-experience questionnaire, which resulted in 39 responses. Note that the total number of participants, including those beyond the survey respondents, was approximately 100 over two days. Many experiences were conducted in groups such as a family. The survey responses were limited to those who experienced the VR system, and the 39

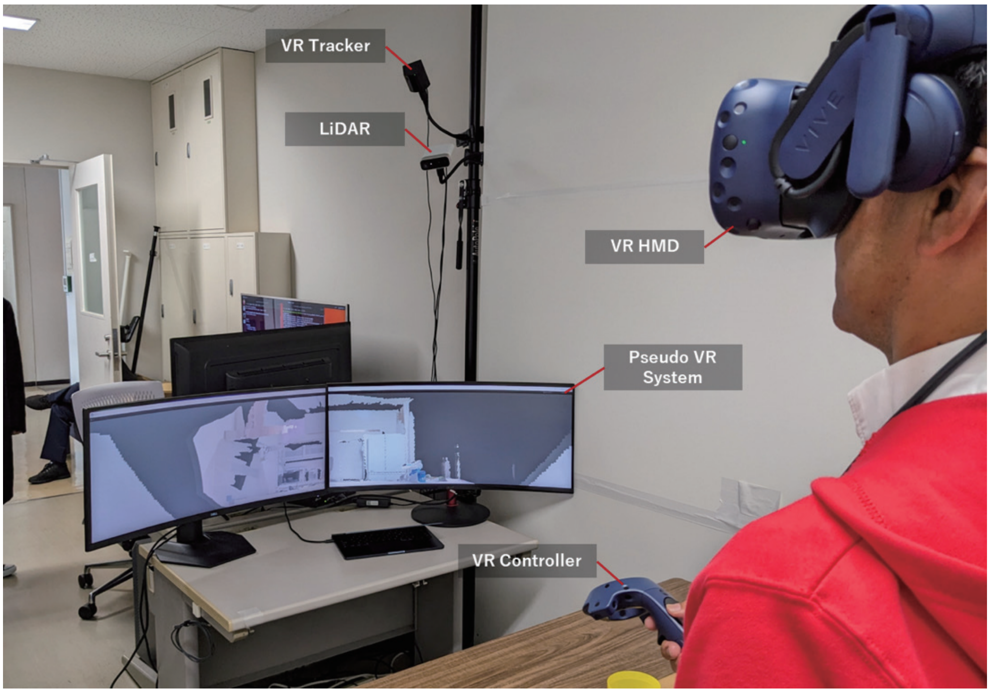


Fig. 3. (Color online) This figure shows the participants using the spatial sharing system. Participants stand in the shared space and wear a VR HMD to explore the 3D reconstructed integrated space.

responses do not include results from participants who only viewed the monitor. Table 1 shows the content of the questionnaire, which included basic information such as age, gender, and familiarity with technology, as well as questions about the system's visuals and equipment, interaction within the system, privacy awareness during system use, and the functionality for displaying or hiding objects. Responses were given using a 5-point Likert scale (strongly agree: 5; agree: 4; neither agree nor disagree: 3; disagree: 2; strongly disagree: 1), and the results were scored accordingly.

5.1 Summary of results

In this section, we provide an overview of the results. The general tendencies in the survey responses were fundamentally similar to those in previous studies.[4] In the previous study, it was hard to detect statistically significant differences. In the current analysis, we collected a sufficient number of samples to conduct the statistical analysis. Specifically, while the previous study had 16 valid responses, this paper emphasizes the findings obtained by analyzing 39 valid responses.

The interactions facilitated by the system were generally well-received, with many participants indicating that sharing space further promoted interaction compared with traditional systems such as Zoom or phone-based communications. However, many low ratings regarding video quality and latency were observed. They were attributed to network bandwidth limitations and rendering capabilities stemming from the real-time transmission of point cloud data.

Table 1
Contents of questionnaire.

Category	Survey Questions
Personal information	- Your age - Your gender - Number of co-inhabitants (excluding yourself)
Basic questions about you	- Knowledgeable about Information Technology - Knowledgeable about VR - Regularly interested in information technology - Regularly interact with distant family
Questions about spatial sharing system's image and equipment	- The image is clear - The image has latency (delay) - The image has a sense of presence - Satisfied with the image - Head or eyes tired from wearing equipment - Operation is intuitive - More difficult to operate than keyboard or mouse - More difficult to operate than phones
Questions about interaction using spatial sharing system	- Natural transmission of each other's movements - Natural transmission of each other's emotions - Natural interaction with the other party - The system facilitates and encourages interaction - More satisfied than using phones - More satisfied than using PC-based meeting tools (e.g., Zoom) - More engaging conversations than using phones - More convenient than using PC-based meeting tools (e.g., Zoom) - More convenient than using phones - More engaging conversations than using PC-based meeting tools (e.g., Zoom) - Satisfied with interaction using the system- prefer to use this system over phones for interaction - Prefer to use this system over PC-based meeting tools (e.g., Zoom) for interaction
Questions about privacy awareness using spatial sharing system	- Anxious about my space being reproduced in VR space - Anxious about sharing my space with others - More privacy concerns than using PC-based meeting tools - More privacy concerns than using phones for communication - Desire to limit sharing range depending on the other party
Questions about the function to hide/replace various objects in spatial sharing system	- Necessity of this function - Desire to use this function - Presence impaired by this function - Privacy protection with this function - Satisfied with this function
Open-ended questions	- Comments on spatial sharing system's image and equipment - Comments on interaction using spatial sharing system - Comments on privacy awareness using spatial sharing system - Comments on the function to hide/replace various objects in spatial sharing system - General feedback on the experience

Moreover, the result shows that the proposed system raises more privacy concerns than typical communication tools such as Zoom or phone-based communications. Females were found to have consistently higher privacy concerns than males. It also suggests that devising the privacy control interface is crucial for elderly people. Detailed results are given in each section.

In this experiment, participants were instructed to engage with the scenario under the assumption of remote family communication, but no further context was provided. Although the results obtained offer insights into general contexts, developing higher-quality privacy filtering functions will require considering privacy requirements and designing systems tailored to various contexts and use cases.[22]

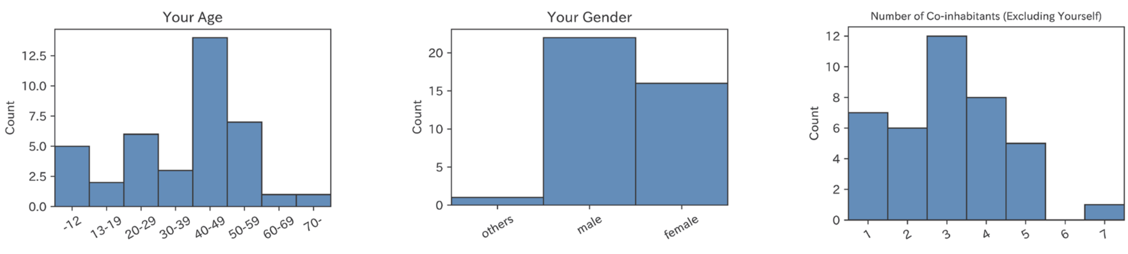
5.2 Overall results and tendencies of the questionnaire

In this section, we provide the overall results and tendencies of the questionnaire. Figure 4 shows the participants' information. However, the age is categorized in the figure (e.g., up to 12 years old, 13 to 19 years old, and 20 to 30 years old) instead of showing the actual values. Although participants were recruited from a wide range, the majority were in their 40s, and the number of male participants was slightly higher.

Figure 5 shows the results of the basic questions asked to the participants. The responses were obtained from a diverse group, including individuals with varying levels of knowledge about technology. On the other hand, the number of people who know about VR was limited.

Figure 6 shows the results of questions regarding video and equipment. Owing to system limitations, multiple responses indicated concerns about video quality and latency. However, many responses also indicated a sense of immersion in the system's video, suggesting that a highly immersive prototype system was constructed.

Figure 7 shows the responses to questions regarding the quality of system interactions. Overall, the system was rated better than traditional communication methods such as phone



(a) (b) (c)

Fig. 4. (Color online) Results of questions about personal information. (a) Age group. (b) Gender. (c) Number of co-inhabitants.

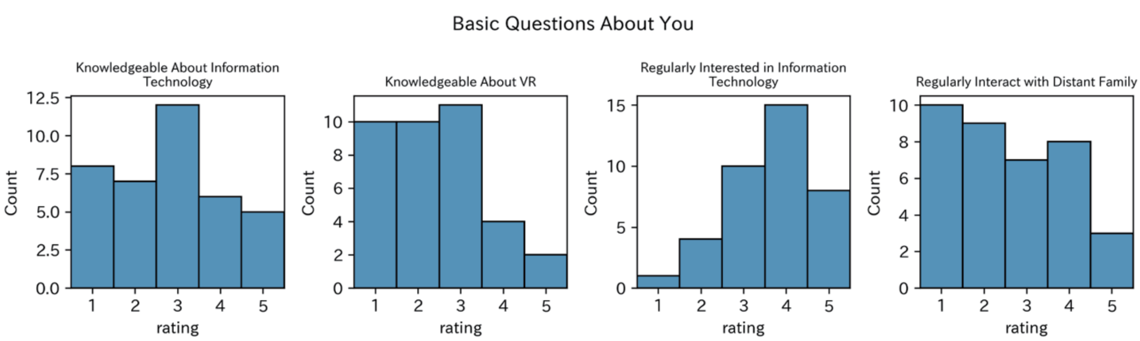


Fig. 5. (Color online) Results of basic questions.

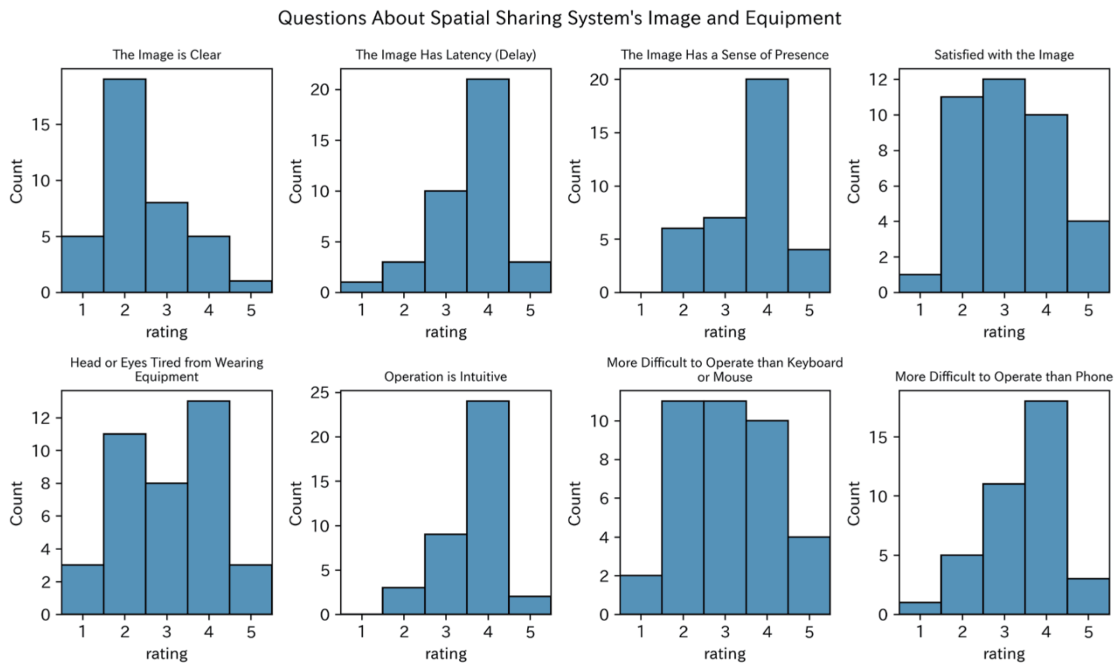


Fig. 6. (Color online) Results of questions about spatial sharing system's image and equipment.

calls or communication applications, indicating its usefulness. However, as shown in Fig. 8, privacy awareness when using the system differed from traditional communication methods, with more privacy concerns. Figure 9 shows the survey results on whether the feature to change the display state of objects is necessary. This feature is essential to address the concerns about privacy issues mentioned above, and it is clear that there is a high demand for such a feature. In particular, the results show that privacy protection features on spatial sharing systems are important for all persons, regardless of gender or age group.

5.3 Results of statistical analysis by gender

In this experiment, responses were obtained from 22 males and 16 females. Given the differences in sample sizes and the possibility that the responses do not follow a normal distribution, the Mann–Whitney U test was used to analyze whether there were significant differences in responses by gender. The responses were divided by gender, and the Python SciPy package was used to test for significant differences in results. Note that one response, where the participant chose not to disclose their gender, was excluded from this analysis.

Table 2 shows the question categories, the content of questions, and p-values for which significant differences ($p < 0.05$) were observed. The results indicate significant gender differences in basic question and privacy awareness items. The basic question items mainly observed differences in familiarity and interest in IT technologies. This suggests that a lack of familiarity with information technology might lead to anxiety about using unfamiliar technologies. In the privacy awareness items regarding spatial sharing, there were notable

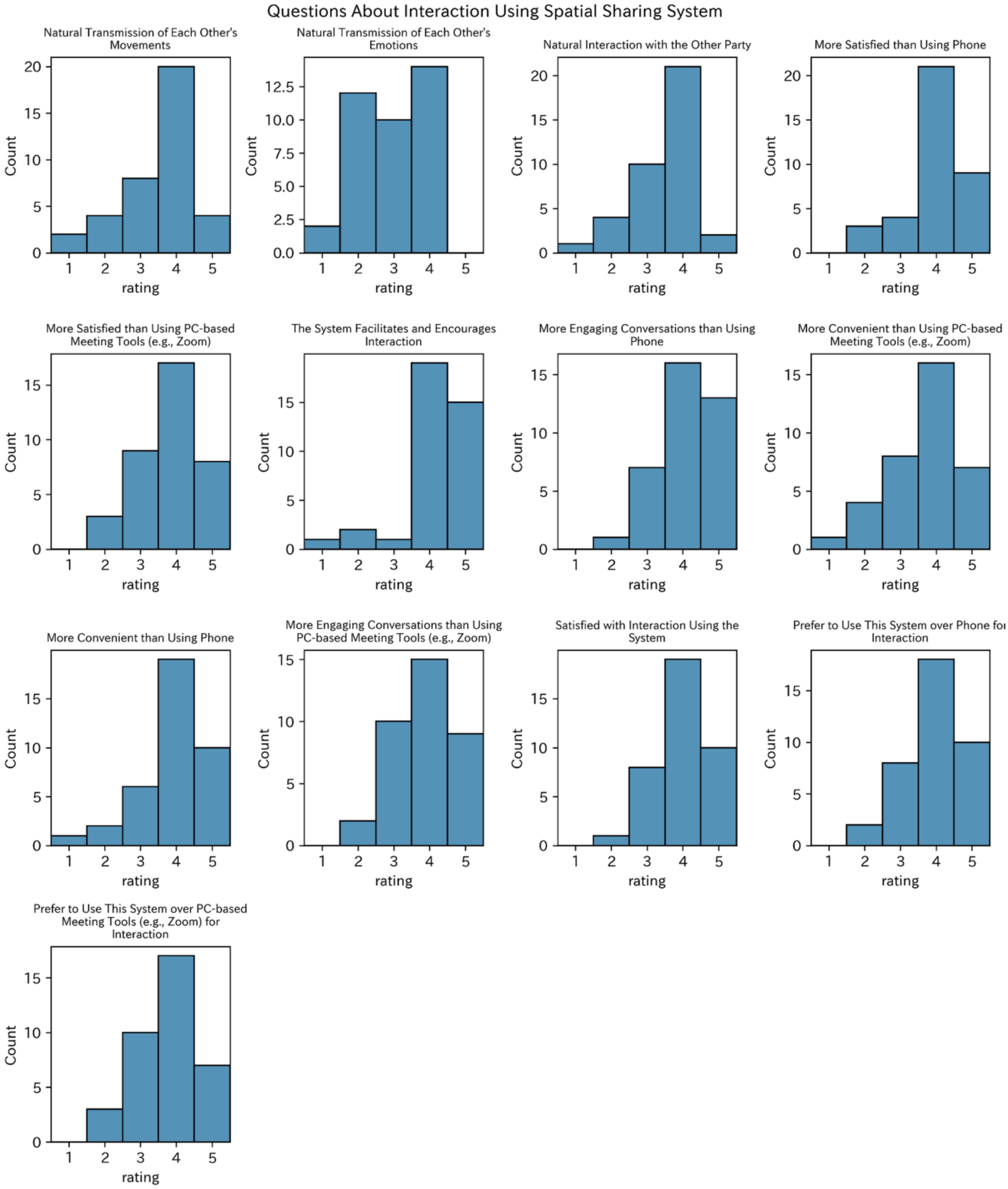


Fig. 7. (Color online) Results of questions about interaction using spatial sharing system.

concerns about the anxiety of having one's space captured in a virtual environment and shared with others, as well as greater privacy concerns than phone communication.

Additionally, the Kruskal–Wallis test was conducted to examine the interaction between gender and the result of "Knowledgeable about Information Technology" on the privacy awareness question items. The results indicated no significant differences ($p > 0.05$) for the

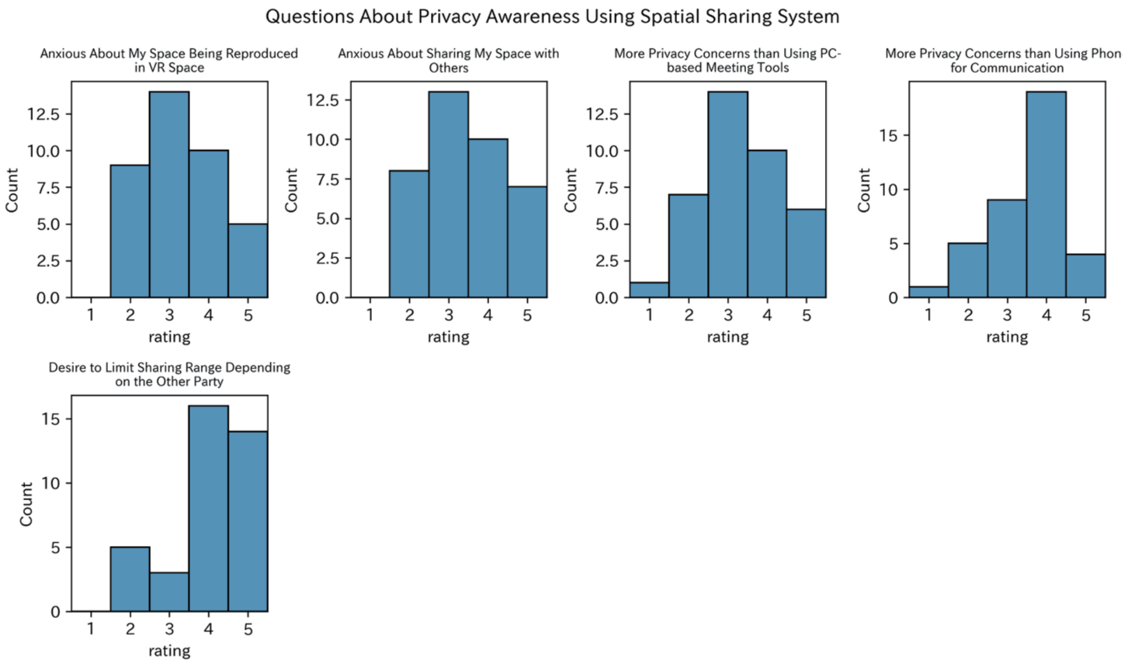


Fig. 8. (Color online) Results of questions about privacy awareness using spatial sharing system.

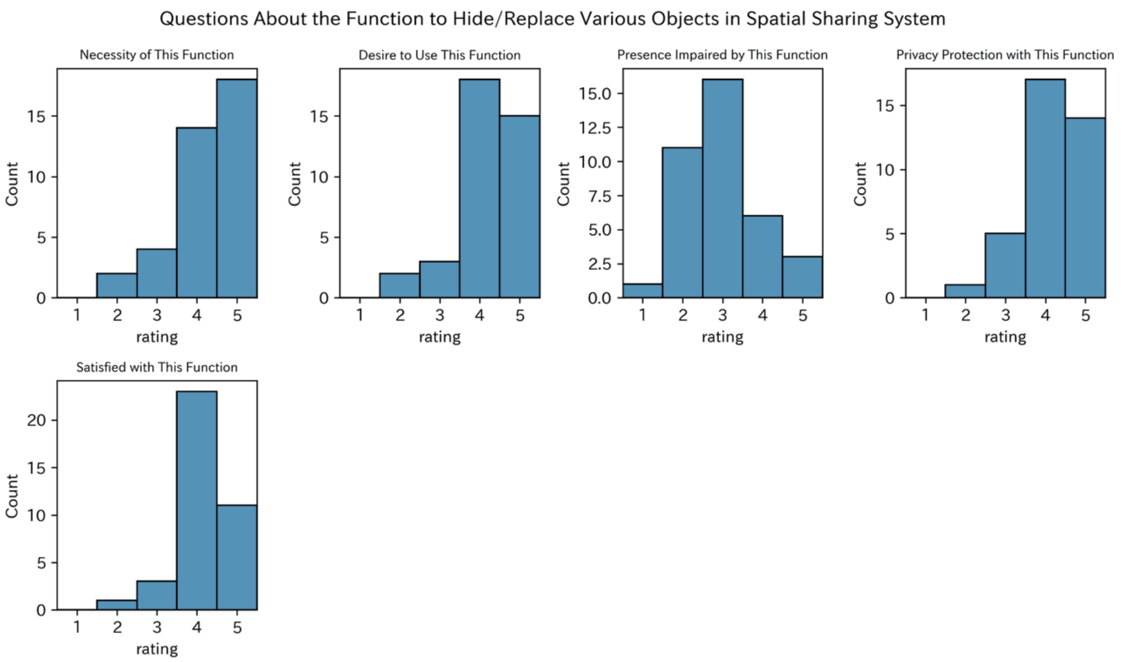


Fig. 9. (Color online) Results of questions about the function to hide/replace various objects in spatial sharing system.

items "Anxious About My Space Being Reproduced in VR Space" and "More Privacy Concerns than Using Phone for Communication". However, a significant difference ($p < 0.05$) was found

Table 2
Questions with observed significant differences by gender ($p < 0.05$).

Category	Question	p-value
Basic questions about you	Knowledgeable about information technology	0.0010
	Knowledgeable about VR	0.0020
	Regularly interested in information technology	0.0067
Questions about privacy awareness using spatial sharing system	Anxious about my space being reproduced in VR space	0.0057
	Anxious about sharing my space with others	0.0030
	More privacy concerns than using phones for communication	0.0444

for the item "Anxious About Sharing My Space with Others". Specifically, the results revealed that males showed greater anxiety about sharing their space with others as their familiarity with information technology increased. In contrast, females consistently showed high levels of anxiety regardless of their IT knowledge. In all cases, it was found that females tend to feel more anxiety than males on various points.

5.4 Results and statistical analysis by age group

To investigate the impact of age on the results, the data was divided by age group, and the Mann–Whitney U test was conducted. Considering the data distribution and to equalize the sample sizes, the data was divided into those below age 40 and those aged 40 and older. As a result, there were 16 data points for those below 40 and 23 data points for those 40 and older.

The items that showed significant differences are shown in Table 3. The table shows that the main differences by age group are in the perception of the video and the acceptance of the devices used. For the questions about the spatial sharing system's image, the group aged 40 and older found the video less immersive than the group below 40. Additionally, it was revealed that the group aged 40 and older was less satisfied with the video. This is likely because the prototype of the spatial sharing system developed for this study represents the video as a 3D point cloud in a virtual space. People below 40 are more likely to be regularly exposed to newer content aimed at younger audiences, making them more receptive to VR content and 3D computer graphics.

Additionally, for the questions about the spatial sharing system's equipment, the group aged 40 and older agreed more with the statement, "More difficult to operate than keyboard or mouse". The current prototype system uses a controller for general VR equipment to operate one's virtual viewpoint. Therefore, similar to the perception of the video, the group aged 40 and older found the VR device controllers, which are relatively new devices, to be less acceptable and more difficult to use. On the other hand, no significant differences were observed in the privacy awareness question items based on age. Therefore, the parameters requiring adjustment according to age differences are related to the representation and operability of the video. However, the representation and operability of the privacy filtering system significantly impact the overall acceptance of the system. In particular, if users want to change the privacy level of each object in real time according to their preferences, the interface quality becomes even more important. In other words, for a system targeting a wide age range, it is necessary to not only model privacy requirements but also aim to improve system usability.

Table 3
Questions with observed significant differences by age group ($p < 0.05$).

Category	Question	p-value
Questions about spatial sharing system's image	The image has a sense of presence	0.0079
	Satisfied with the image	0.0038
Questions about spatial sharing system's equipment	More difficult to operate than keyboard or mouse	0.0180

6. Conclusion

In this study, we investigated the privacy awareness that arises when using a spatial sharing system that scans participants' physical spaces as 3D spaces. We received 39 responses from participants and performed statistical analyses mainly based on differences in gender and age group. The results revealed that the spatial sharing system enhances the quality of the experience compared with traditional communication methods. However, significant privacy concerns unique to such a system were also highlighted, indicating a demand for privacy protection features.

The gender-based analysis showed significant differences in items such as "Anxious About Sharing My Space with Others" and "More Privacy Concerns than Using Phone for Communication". Additionally, differences in age group suggested varying acceptance levels of the rendered video and interface.

Through the system's trial sessions, we investigated changes in privacy awareness during spatial sharing. However, we have not yet collected data on privacy requirements from actual daily use. Therefore, it is essential to install spatial sharing systems in real households and collect similar survey data to investigate privacy awareness in future studies. Moreover, the privacy requirements may change depending on the video quality of the system. Consequently, developing systems capable of supporting large-scale, high-speed data transmission infrastructure and improvements in rendering quality are required.

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