DHH People in Co-located Collaborative Multiplayer AR Environments

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ABSTRACT

Deaf and hard of hearing (DHH) people often require assistive environments or technologies while communicating, and there have been several technologies and studies to serve this purpose, namely augmented reality (AR). Although technical aspects and users' behavior with these technologies have been covered in plenty of prior literature, very few studies have paid attention to how DHH people communicate, collaborate, and coordinate in co-located collaborative AR environments. After reviewing the literature, I present a primary agenda consisting of an iterative research plan that uses qualitative and quantitative methodologies to address the knowledge gap. Furthermore, I discuss the initial findings from my previous research, followed by suggestions for future work.

CCS CONCEPTS

• **Human-centered computing** → **Accesibility**; **Mixed / Augmented reality**.

KEYWORDS

Human-computer Interaction; Accessibility; Augmented Reality

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1 INTRODUCTION

About 430 million people, or over 5% of the world's population, are deaf or hard of hearing [4]. The term "deaf" generally refers to hearing loss to such an extent that the person has very little to no functional hearing at all, whereas "hard of hearing" refers to individuals with enough residual hearing that can be aided with auditory devices (hearing aids or FM systems) that can help them process speech [2]. Being one of the linguistic minority groups [15, 16], deaf and hard of hearing (DHH) people often require assistive technologies and accessible environments to facilitate communication with individuals who are not accustomed to their way of communicating, such as sign language [9, 21]. There have been a plethora of technologies (e.g., [1, 3])and studies (e.g.,[13, 22]) to address this issue, AR technology being one of them.

However, existing studies regarding AR mostly focus on the technical aspects or report on the system's accuracy [11, 23]. Even though collaboration among multiple users simultaneously has been considered a major factor in AR technology for a long time [6, 12, 18], very few studies have been conducted to understand the communication and collaboration aspects of co-located collaborative multiplayer AR environments. The number of literary works is even lower, where the work focuses on DHH participants and their communication and collaborative behaviors with each other rather than the system itself. As a result, there continue to be significant gaps in our understanding of the communication and collaborative behaviors of DHH users in co-located collaborative multiplayer AR environments, which further impacts our comprehension of the challenges DHH users face while communicating and collaborating in these environments and ways to address those challenges so these environments can be inclusive for all.

My research focuses on the communication, collaboration, and coordination aspects of DHH users in co-located collaborative multiplayer AR environments, the challenges DHH users experience in such environments, and users' recommended ways to overcome the challenges. This research will provide a more precise answer to how DHH users communicate and collaborate with other DHH users, what kinds of issues they face, and improvements and strategies to incorporate from a technical standpoint to overcome the issues in these environments. The following three questions will serve as my guide during the preliminary stages of my doctoral research:

RQ1: How do DHH users communicate, collaborate, and coordinate in co-located collaborative multiplayer AR environments?

RQ2: What challenges do DHH users face while communicating and collaborating in co-located collaborative multiplayer AR environments?

RQ3: What are the ways to address these challenges to make co-located collaborative multiplayer AR environments more accessible for DHH users?

2 BACKGROUND

Several studies have shown how AR can act as an accessible technology [26] for DHH people. For instance, Mirzaei et al. [23] presented a system combining AR, ASR, and TTS, where the system takes speech from the speaker in real-time, converts it into readable text, and shows it on the AR display. Peng et al. [24] contributed to the domain of real-time captioning using AR by codesigning a system

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that can associate, order, display optimal length of content, and visualize the utterances of different speakers even if they are out of view. In another study by Guo et al. [11], they introduced a HoloLens-based AR prototype called *HoloSound*, where they used deep learning to classify and visualize sound identity and location along with speech transcription. With the intention of personalizing television content with an added sign language interpreter in the display area using AR, Vinayagamoorthy, and Ziegler [27] conducted a study and they focused more on users' feedback on the system. Luo et al. [19] developed a system called *Avatar Interpreter* that can translate speech into Chinese Sign Language (CSL) in real-time, where the virtual interpreter could be put in different positions according to the user's needs in classroom environments. All of these works paid attention to either the system's design, implementation, accuracy, or users' interaction with the system. No AR system or environment has been used to point out how DHH users communicate with each other in AR environments, which further indicates the large gaps in our understanding.

On the other hand, in a study about collaborative approaches to solving lines and angles-related problems using AR, Sarkar et al. [25] found that the majority of the participants (90.4%) preferred collaboration while using AR in learning activities. In another study by Huynh and colleagues [14], they concluded that collaborative AR games could simulate social interaction, including verbal and non-verbal communication (e.g., hand gestures and body language), even though the players are strangers when they start the game. Focusing more on social interaction, in another study by Xu et al. [28], they designed a prototype called Bragfish as a part of their exploration and further evaluated the prototype, which illustrated how participants formed strategies for social play by using various cues (e.g., visual, aural, and physical) in a shared environment. Another study by Franz et al. [10] consisted of shared AR experiences in a museum setting, and one of their findings was that participants using shared AR views stayed together in a group and communicated with each other more, indicating more engagement compared to the participants who were using private AR views. All of the above-mentioned studies were conducted with participants who were not DDH, which indicates a lack of inclusivity and further solidifies the gap in our knowledge about the communication and collaboration behaviors of DHH participants in co-located and collaborative multiplayer AR environments.

3 METHODOLOGY

I plan to conduct several studies using a new co-located collaborative multiplayer AR environment. Based on the AR environment, I will create semi-structured interview questions [5] that I will use to collect qualitative data. The following steps will be to recruit DHH participants, conduct experiments, and conduct one-on-one interviews. Furthermore, while overseeing the experiments, I will collect observational data that I will later employ alongside the qualitative data in the data analysis phase.

Qualitative data is more prominent due to the nature of my research, and a semi-structured interview is one of the most suitable options to gather qualitative data because it will let me improvise and ask follow-up questions as required. Furthermore, I will also be able to cater to each participant's preferred mode of communication (e.g., verbal or text-based interviews). A major portion of my interview questions will be about users' personal experiences of communicating, collaborating, and coordinating in the co-located collaborative multiplayer AR environment, their challenges, and their recommendations to overcome them. Moreover, I plan to gather quantitative data that I will initially use to recruit participants for my studies. Additionally, quantitative data will give me better insight into the demographics (e.g., age, gender, preferred methods of communication, and level of familiarity with AR). They will also help me determine inconsistencies between user-provided and actual data (e.g., duration of a game round and duration between each round).

In the data analysis phase, I will concentrate more on analyzing the qualitative data from the interviews and experimental observation. I intend to utilize reflexive thematic analysis (RTA) [7] since this approach would give me the flexibility to organize codes and develop themes around them. As I will progress through my analysis, I can become more familiar with the data. As a result, it will give me more freedom in the interpretation of new patterns. In terms of coding and identifying themes, I will employ semantic and latent approaches [17]. The reason for choosing both semantic and latent approaches is that the first will help me identify, organize, and interpret recurring themes on the surface level of the data. The latter will allow me to go beyond what I achieve in the semantic approach by revealing underlying meanings and connotations. I can further develop specific answers for my research questions based on the frequently found themes. However, as my research progresses, I might need to leverage various statistical methods (e.g., standard deviation, hypothesis testing, regression, etc.) for analyzing quantitative data based on the specifications of my future experiments. So far, I have conducted one study leveraging the discussed methodology and used the semantic and latent TA approach to analyze collected data.

4 FINDINGS AND DISCUSSION

In Study One, I followed the methodology discussed in the prior section and focused mostly on RQ1, but also gathered some initial findings regarding RQ2 and RQ3. Some of the prominent initial findings were, 1) communication between players affects collaboration before and during the game; 2) players use multi-modal communication (hand gestures, body language) before and during the game when they cannot communicate verbally; 3) players coordination with AR components, other players, and the surroundings gets better with each round, but communication and collaboration reduce as they get used to the game; 4) technical issues and game design can negatively affect communication when players are using multi-modal communication; and 5) the design of the game should be improved with visual cues for DHH players.

The results from this study point toward the fact that DHH players improvised their communication and collaboration tactics, and non-verbal communication played an effective and positive role in this particular AR environment, similar to social VR environments [20]. Furthermore, the more they communicated, the better they could collaborate before and during the game. Although co-located settings have a higher social presence measure, players can still experience varying degrees of awareness, involvement, and engagement [8]. Nevertheless, in this particular AR environment, players were getting better at coordinating with other players, the physical environment, and the AR components as the game progressed. However, as they became more accustomed to the game, they developed a greater sense of independence and did not need as much help from other players, further decreasing the need for interaction and teamwork.

Furthermore, some players faced technical issues (e.g., game lag, sudden shutdown of the game, failure to enter the game session) during their game, which affected their communication with other players. Players suggested adding more content and levels would foster deeper communication and collaboration. Surprisingly, players did not want any in-game communication (e.g., text-based interaction or speech-to-text interaction); rather, they wanted the game design to be improved with visual cues for DHH players who could not reciprocate verbal cues. As the reason behind this recommendation, they mentioned that the game is fast-paced and in-game communication would only slow it down.

5 LIMITATIONS

In my prior study, all the participants were accustomed to AR technology even if the particular AR probe used in the experiment was new to them. However, participants' overall understanding of AR environments, how to cooperate and collaborate in such environments, and their willingness to participate in stimulating social interaction might be major factors in determining their challenges.

6 FUTURE WORK

Finding the behavior pattern of DHH users in co-located collaborative multiplayer AR environment (RQ1) was the primary focus of my prior study, so I will be shifting my attention to what kind of challenges they face in such environments (RQ2) in the coming research. I will employ a different AR environment and concentrate more on the challenges DHH participants experience in the new setting. I anticipate that I will come across some intriguing results that will clarify some of the unique challenges that DHH players in these settings face. I can also identify some overarching challenges that the DHH players encountered in both settings, which will help me produce a more thorough response to my RQ2. Furthermore, I hope that I will gain a deeper comprehension of how DHH players behave when they communicate, collaborate, and coordinate in these settings (RQ1), as well as their viewpoint on making these environments more inclusive (RQ3).

7 CONCLUSION

My research aims to investigate how DHH people communicate, collaborate, and coordinate in co-located collaborative multiplayer AR environments, what kind of challenges they face, and how to make these environments more accommodating and inclusive for them from the DHH user's perspective. I intend to conduct several studies repetitively, where each study will contribute to coming up with comprehensible answers to my research questions. I have so far conducted one study, and I have some preliminary findings about the behavior patterns of DHH participants in this particular environment concerning collaboration, communication, and coordination. However, I plan to conduct several studies, each with a different AR environment, to discover the generalized and environment-specific challenges that DHH people experience and ways to overcome them. This will further help bridge the knowledge gap in the present literature.

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