Engagement and Quality of Experience in Remote Business Meetings: A Social VR Study

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Figure 1: Social VR system, where users are represented as point clouds in a virtual office

ABSTRACT

Currently, most videoconferencing technologies do not keep employees sufficiently engaged during business meetings. Recent studies have shown how extended reality (XR) technologies can help in executing remote meetings in new and possibly better ways. One important factor for meetings in e.g. Virtual Reality (VR) is avatar realism, with the assumption that photorealistic representations of users increase the engagement during meetings compared to a model-based graphical representation. However, so far only limited studies have been conducted in a real-world setting with a social virtual reality communication system in which users are represented as photorealistic avatars. Therefore, in this paper, we present a pilot study using a social VR communication system that allows employees of an organisation to meet each other from different remote office locations in The Netherlands. The users are captured with a depth camera, after which the capture is rendered in the HMD's of the users. Furthermore, the research provides a novel way to subjectively investigate the engagement and quality of experience (QoE) in social VR in real-world settings and long-term use. Our correlation analysis shows that there are strong linear relationships between the quality of communication, embodiment, immersion, social presence, and meeting-engagement. Furthermore, there are strong linear relationships between usability, quality of interaction, and quality of experience.

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CCS CONCEPTS

• **Human-centered computing** → **HCI design and evaluation methods**; **User studies**; **Virtual reality**; **Collaborative interaction**.

KEYWORDS

Social Virtual Reality, Quality of Experience, QoE, Engagement, Quality of Service, QoS, Remote Meetings, Computer-mediated communication, CMC

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1 INTRODUCTION

It has long been recognised that the most effective and engaging way of conducting business meetings is by meeting face-to-face (f2f) [8]. One of the reasons is that there is a lack of engagement and effectiveness in current 2D videoconferencing meetings. Common issues encountered by meeting participants are background noise, a lack of social presence and not knowing who is speaking. These issues most often occur in meetings with many participants [17].

However, especially since the COVID-19 pandemic, remote meetings have become more and more part of the workplace routines. Therefore, it is essential to know how remote meetings can promote more productive and engaged attitudes [6].

Current videoconferencing methods do not convey a sense of co-presence, as there is no shared visual context [4]. Furthermore, the parallax between the screen and the camera makes it difficult to establish a mutual eye gaze [23]. Moreover, when deictic utterances (words such as: 'that', 'there', 'those') and gestures are well supported in a working/meeting environment, the resulting communication between participants is much more efficient, task performance increases, and users rate the quality of experience higher [23]. Proper communication of relevant social signals in a meeting is the reason why virtual reality (VR) technology has the potential to support communication at a level close to f2f communication [12, 18]. Since both Quality of Experience (QoE) and social presence in VR are higher, engagement may also be higher in social VR meetings. The research presented in [5] also hypothesised that employees in VR meetings will be more engaged and focused than during "regular" video meetings. However, the relationship between these variables has not yet been defined, especially in the context of remote real-world meetings in which a social VR communication system that includes photorealistic user representation is used.

To carry out our pilot study, we built a novel communication system and deployed it in four offices in three cities in the Netherlands. The purpose of the research is to contextualise the relationship between QoE and perceived engagement in subsequent business meetings using a photorealistic social virtual reality communication system. A secondary goal is to investigate the relationship of the variables mentioned above with subjective quality of service (QoS).

2 RELATED WORK

Social presence and immersion are essential to create more realistic and engaging VR experiences for social interactions by making these interactions more clear and direct [15, 27]. Together, these concepts create engaging experiences in which the line between reality and imagination is blurred [20]. Furthermore, body representation and everything it involves plays a role in these immersive virtual environments and can also help create more engaging experiences [15]. Non-verbal cues, such as body language, slight changes in posture, use of gestures, and initiating or withdrawing from conversations, are all essential parts in communicative interactions. These non-verbal cues can easily be conveyed in social VR environments. This can be evaluated with the quality of communication (QoC) metric, which grasps the naturalness of a conversation, the degree of participation in the conversation, a sense of co-presence with the other, and an evaluation of the conversation partner [10].

On the other hand, quality of interaction (QoI) is also an important element to evaluate. In addition to the higher sense of immersion, engagement and presence that VR-based systems provide, they also provide a shared meeting space for users to interact [14]. Due to virtual reality systems in the consumer market, it is becoming easier for remote users to inhabit the same virtual environment and engage in a common activity [13]. The engagement can then be felt at the individual level, but also in the context of group-social interaction [25]. Furthermore, the usability of the system itself also has an influence on engagement. Usability refers to the affective (frustration) and cognitive (effortful) aspects of using the system that contribute to a general sense of user engagement [25]. Usability with respect to VR also includes the comfort of users with immersion and presence [21].

Furthermore, embodiment plays a key role in achieving a high social presence in social VR experiences [13]. Embodied VR in which a full-body avatar was used and user movements were rendered in the avatar led to conversation patterns and interactions with other users that were almost similar to f2f communication [23]. The reason why these patterns may be similar is that embodied experiences in VR create the feeling of personally experiencing with your own body [20]. For users, it seems that the actions of their avatars are actually their own. Users can feel the VR components as part of their own bodies and perceive themselves as part of the VR environment [1].

In summary, embodiment appears to contribute positively to engagement [20], as do social presence, immersion, QoI, QoC and usability [14, 15, 21]. All the different aspects that are related to the VR experience of a user can be combined in a multidisciplinary indicator, widely recognised as quality of experience (QoE) [19]. QoE is considered to be made up not only of perceivable technical aspects of a system, but also of numerous other human and contextual aspects. Therefore, it is a complex cognitive construct that is formed within the mind of a user [22]. The interactive and immersive nature of VR disrupts this QoE metric, as VR has a much different impact than normal 2D videoconferencing systems [19].

In addition, there are technical quality of service (QoS) parameters that have an influence on QoE [7, 19]. However, it may be possible that the technical quality of VR systems might not directly influence the performance, value, or experiences of VR users [20]. Aspects such as immersion have a huge effect on QoE in addition to QoS parameters [20]. However, so far, not much literature has been found showing the relationships of concepts such as immersion, presence, embodiment, and usability of VR systems with each other and with QoE in the context of meeting-engagement. Therefore, the current study will investigate the different concepts that are important in creating engagement in meetings in social VR business meetings.

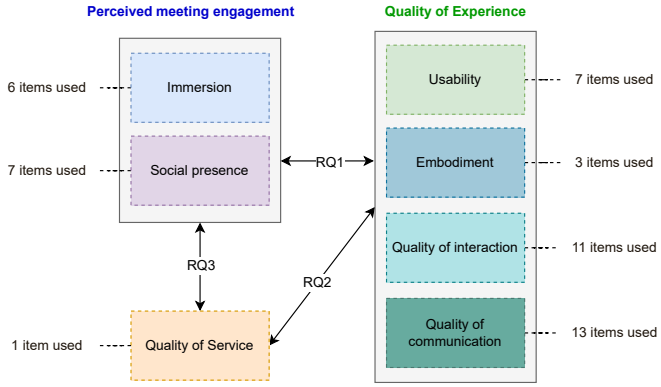
3 METHODOLOGY

3.1 Participants and procedure

The objective of this research is to test the social VR system, which is detailed in the following, with colleagues within the same organisation. There were 12 participants (6 meeting pairs) in total who had either 1 or 2 meetings with each other from different offices in The Netherlands using the Social VR system. Fig. 2a visualizes the various remote office locations in The Netherlands. A line in the map represents the connection of 1 pair.

The age range of the participants is between 20 and 60+ years, with 11 male subjects and 1 female subject. All pairs were already acquainted with each other by working together on projects presently or in the past. In a 12-week period, subsequent meetings were held with each other using the VR system. After each meeting, all participants had to complete a questionnaire that included questions

(a) Participant connections between the different office locations in The Netherlands



(b) Relationship between the variables of the research design

Figure 2: Meeting conditions

from various surveys [2, 3, 10, 11, 16, 24–26] on social presence, immersion, usability, embodiment, quality of interaction, and quality of communication.

3.2 The research design & data analysis

The conceptual model in Fig. 2b presents the different elements that are related to engagement. The current study aims to test whether there are relationships between these elements and how strong these relationships are. Based on the literature, it was decided that perceived meeting-engagement and QoE are composite variables made up of different elements necessary for social VR business meetings. The number of items that were included in the questionnaire for each element is shown in Fig. 2b. A 7-point Likert scale was used for all questions. Pearson correlations will be used to analyse the relationships between the elements. The software that will be used to conduct these correlations is the RStudio IDE (www.rstudio.com).

Since it was possible for the participants to have several meetings with each other using the VR system, data is also obtained on the change in their scores for the different variables. There is a possibility that these insights will show whether or not a first-timer effect has occurred.

In addition to the quantitative analysis, a qualitative analysis will also be performed on the textual data collected from the questionnaires. Several open questions were included so that more information could be gathered on the perceived performance of the system and the users' experiences with the system. The findings will be presented in word clouds centering on specific themes that are found by reading the responses of the participants to the questions.

4 SOCIAL VR SYSTEM

We developed a novel communication tool for the pilot study conducted in this article that integrates 3D photorealistic capture and rendering (RGB + depth) [9] into a commercial VR application and platform, namely Connec2. The capture module used is described in [9] and allows RGBD image processing for 3D user representations, as well as processing and storing of body tracking and voice activity detection (for "privacy aware" post-analysis of the communication behaviour). Our system allows movement in a 3D space with reasonable visual and auditorial spatial awareness (in the ideal view frustum). This is because as we currently only apply a one RGBD camera solution, people are encouraged to keep in a confined space to avoid distortions in the 3D point cloud (i.e. simply parts that are not captured cannot be rendered), which would be a normal situation for a business meeting.

Figure 3 shows the overall architecture and pipeline of our system that consists of the following steps:

(1) The images are captured with a ZED 2i RGBD sensor (720p with 15fps)
(2) RGBD images are processed with a modularised capture tool [9]
  (a) read RGB + Depth data from sensor, process, clean and improve the data
  (b) perform and store body tracking & voice activity detection for "privacy aware" post analysis
  (c) conversion of depth to greyscale image for transmission
  (d) exposure of new RGBD image over a virtual webcam driver (512x1024 pixel resolution)
(3) Ingest client to grab RGBD image from virtual webcam and send to the system
(4) Transmission is done as compressed JPG via structured networked message queue
(5) Render client to receive RGBD image and display users as 3D point cloud (via VFX-graph)
  (a) The rendering client also sends and receives audio for verbal communication
  (b) The client is implemented as a unity Android application for the quest platform running on an Oculus for business HMD (technically identical to the Oculus Quest 2).

5 RESULTS

5.1 Scores and relationships

The quality of communication was rated highest in both meetings, which can be seen in Fig. 4a. The scores on the Likert scale ranged from -3 to 3 with 0 being a neutral score. For the first meeting, embodiment scored the lowest, while for the second meeting, QoS

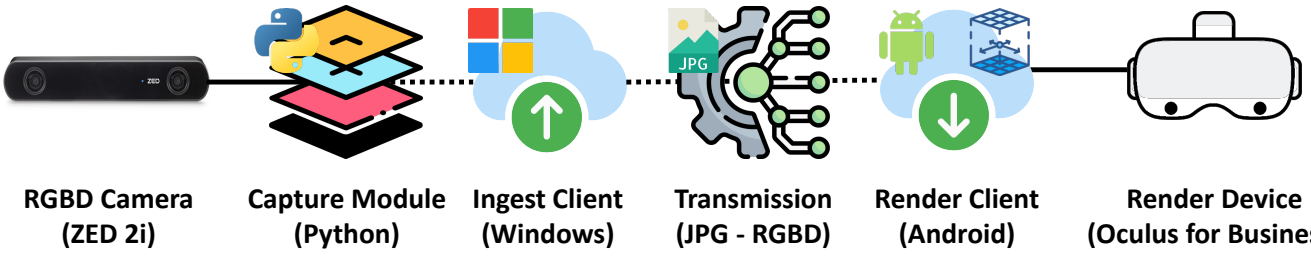
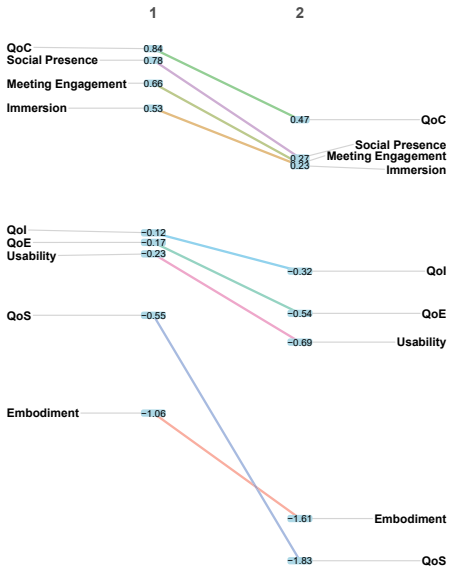
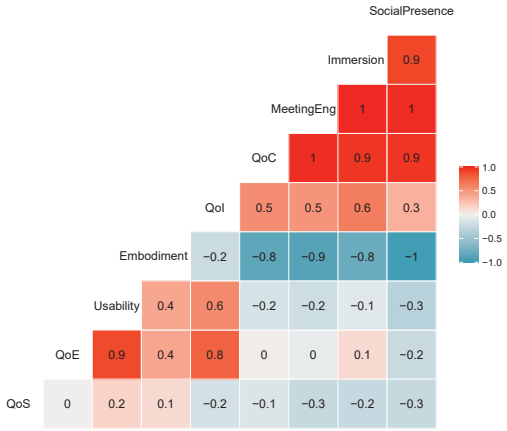


Figure 3: System Architecture Pipeline



(a) Change in scores for elements of meeting 1 and 2



(b) Correlations between different elements

Figure 4: Scores and relationships

scored the lowest (out of all elements). Additionally, all scores for the elements were lower for the second meeting. In particular, the QoS decreased to a greater extent compared to the other elements. It should be noted that all 12 participants had the first meeting and that only 6 participants attended the second meeting. No further statistical analysis was performed on these results due to the small sample size. However, it is safe to assume that the results of the first meeting are, in general, higher than those of the second meeting.

Furthermore, Fig. 4b shows a correlogram showing the correlations between the different elements. The most notable relationships for the research and the findings are presented below:

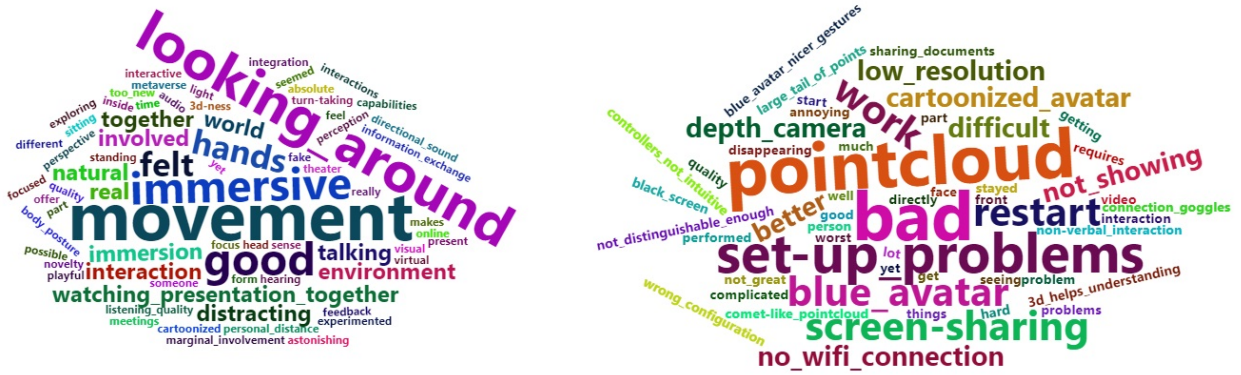
- There is no significant linear relationship between quality of experience and meeting-engagement (RQ1).
- There is no significant linear relationship between quality of service and quality of experience (RQ2).
- There is a weak negative linear relationship between quality of service and meeting-engagement (RQ3).

Although there are no strong relationships between these variables, the correlogram shows that there are strong relationships between some of the elements in the composite variables presented in the following:

(1) There is a strong positive linear relationship between quality of experience and usability.
(2) There is also a strong positive linear relationship between the quality of interaction and quality of experience.
(3) There are strong negative linear relationships between embodiment and quality of communication, meeting-engagement, immersion and social presence.
(4) There is a strong positive linear relationship between quality of interaction and immersion.
(5) There are strong positive linear relationships between quality of communication, immersion, and social presence, and therefore also with meeting-engagement.

5.2 Textual analysis for further insights

The answers to the open questions show that the participants experienced movements in the VR environment that were consistent with real-world experiences. The word cloud in Fig. 5a shows that they expressed that looking around and moving your hands in the VR environment felt the same as when you are looking around and moving your hands in the real world. The same was said about watching a presentation together. Participants also said that the environment was very immersive and natural and that they felt



(a) Words associated with the environment and real-world consistencies

(b) Words associated with point cloud and technical issues

Figure 5: Wordclouds with text from open questions

involved. These insights further explain why social presence, immersion and quality of communication were rated so highly with the closed questions of the questionnaire.

However, some technical problems were encountered, especially with regard to the point cloud. Therefore, it is fair to say that both the quality of service and embodiment have been rated lowly by the participants. The word cloud in Fig. 5b shows that there were problems encountered with setting up the system and that the photorealistic avatars did not appear or had a low resolution. However, the correlogram shows that there is still no strong relationship between QoS and the rest of the elements. Yet, embodiment has a strong negative relationship with some of the elements.

Moreover, the participants also mentioned in the open questions which aspects of the system should be improved for future use. The equipment was mentioned to be heavy and it would be useful to have the equipment at home because it is not practical to go to a specific room in the office. Most of the participants commented that if the photorealistic avatars had been of higher quality, the experience would have been much better. Participants also believe that the system is more valuable when meeting medium to large groups, where you can act more naturally with each other than with MS teams.

6 DISCUSSION AND CONCLUSIONS

In the scope of this study, we evaluate the strength of the relationship between quality of experience, quality of service, and meeting-engagement in social VR business meetings. However, because the research was conducted in a real-world setting, it is naturally almost impossible to control all influencing factors. Some of these factors are related to the physical rooms in which the participants had their meetings. For example, the (wireless) Internet connection at one location was much better than at another location. Furthermore, the participants themselves also had an influence on the research. This is evident from the number of people who participated in the first and second meetings.

However, from the results of the full questionnaire, it is clear that there are strong relationships between some of the elements necessary to create engagement in social VR business meetings. It is also clear that while there were some technical issues when using the system, this barely affected the feelings of immersion, social presence and meeting-engagement. When the quality of service decreased significantly for the second meeting, the rest of the scores for elements did not decrease to the same extent, which could be explained by the high score for the QoC. Participants were still able to converse with each other using the system, and therefore could still have felt present with each other and immersed in the VR environment. Thus, there are no (or weak) linear relationships between subjective QoE, subjective QoS and meeting-engagement.

Yet, it is also clear that different QoE indicators have different types of relationships with meeting-engagement. Usability does not have a linear relationship with meeting-engagement. Moreover, embodiment has a strong negative linear relationship with engagement. On the other hand, QoI does have a moderate relationship with meeting-engagement and QoC has a strong positive relationship with engagement. All in all, embodiment and QoC show very contradictory relationships with meeting-engagement, which leads to no relationship between QoE and engagement. In the future, such conclusions might be different as the user representation as point clouds constantly improves.

In summary, it can be concluded that there is a strong linear relationship between the quality of communication, immersion, social presence, and embodiment. This in turn leads to a strong linear relationship with meeting-engagement as well. The relationship between these metrics needs to be further explored. In addition, the quality of experience, usability, and quality of interaction also correlate strongly and linearly with each other. Our current analysis focused on linear relationships; yet, other types of relationships need to be investigated as well, such as non-linear and monotonic relationships.

For future studies, we plan to study elements of engagement in a more controlled setting. Participants could plan several meetings with each other, after which they are given tasks to do in the meeting, such as presenting a given slide set or taking notes. Furthermore, eye tracking software can also be used in the future to objectively detect how engaged or disengaged participants are. Further objective communication metrics can be acquired by body-tracking, like body postures and the use of gestures, providing further details on the engaged states of users.

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