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PSCVR: Physiological Sensing in Collaborative Virtual Reality

Prasanth Sasikumar*
Auckland Bioengineering Institute, University of Auckland, New Zealand

Yun Suen Pai†
Keio University Graduate School of Media Design, Yokohama, Japan.

Huidong Bai‡
Auckland Bioengineering Institute, University of Auckland, New Zealand

Mark Billinghurst§
ITMS, University of South Australia, Mawson Lakes, Australia

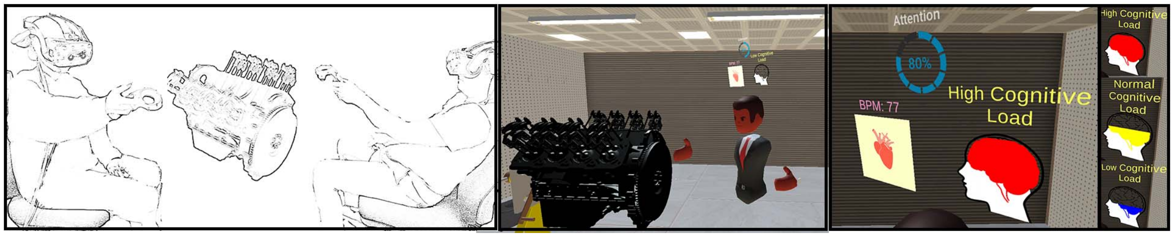

Figure 1: a) Participants performing actions on a digital replica of an engine. b) First person view of the collaborator, c)Visual representation of physiological signals, d) Various states of cognitive load.

ABSTRACT

In a collaborative environment where more than a single user need to complete a task together, being able to understand each other's emotional status is essential for a successful outcome. This is especially evident in remote collaboration tasks where the physical distance may create a lack of understanding, empathy, and comprehension between the partners. Typical remote collaboration systems share less information than that can be communicated in a physical interaction, which makes supporting awareness very challenging. Our proposed visual representation allows users to infer emotional patterns from physiological data, which could impact their communication style towards a more forceful or inactive and calm association.

We investigate the potential effects of the proposed visual representation to support empathetic communication during remote collaboration, as well as the design guidelines for building such systems.

Index Terms: Human-centered computing—Visualization—Visualization techniques—Treemaps; Human-centered computing—Visualization—Visualization design and evaluation methods

1 INTRODUCTION

With the recent popularity of video conferencing tools due to the pandemic, many people choose to work, study, and play remotely. Most tools for remote collaboration are web/desktop based. However, some may discover the limitations of these tools when they try to present 3D spatial concepts or convey natural non-verbal communication cues through 2D camera feeds. For example, teaching an engine repair course that involves a large number of parts can be confusing when watched through a real-time video. To showcase such a scenario effectively with the live video would require shots from multiple angles switched and shown at the right time. A potential solution is to enable users to present themselves and their ideas more interactively in Virtual Reality (VR) and deliver much more information than 2D camera video.

The role of physiological cues in remote collaboration has been studied by many researchers [26]. With the advent of low-cost VR devices, there is a steady rise in the number of collaboration platforms providing rich interactive experiences. Applications such as Spatial.io (https://spatial.io/), AltspaceVR (https://altvr.com/), Facebook Horizon(https://www.oculus.com/facebook-horizon/), Mozilla Hubs (https://hubs.mozilla.com/), etc. provide a standalone platform to collaborate with VR. However, these systems lack the integration of sharing physiological cues, which is the primary motivation behind the development.

PSCVR solves this problem by sharing physiological cues like the hear-rate, cognitive load, and attention of the collaborator between collaborators to enable a better mutual understanding. We have proposed a user study to test the hypothesis that using visualization of physiological cues would significantly improve empathy levels. We leverage VR's ability to showcase natural non-verbal communication cues and physiological sensing to provide a richer experience from within the traditional remote collaboration platforms.

2 RELATED WORK

VR-mediated experiences can help interact with one another in scenarios where participants are not located in the same physical space. This could take the form of two participants joining each other in an entirely virtual environment from separate physical spaces by entering the same VR world.

2.1 Social VR

Collaboration is one of the most compelling use cases for immersive VR. This is mainly due to the ability of VR systems to track and represent the user in a natural way just like the face-to-face experience. Some early academic VR systems demonstrated the potential of collaboration in VR [6, 7, 20]. Many researchers have studied the representation of the user as an avatar and the social response they generate. A wide variety of new VR applications are being developed due to the recent interest in consumer VR. Over 100 systems are listed in the XR collaboration directory that works with a minimum of two collaborators [1].

2.2 Effect of sharing physiological cues

Thompson [27] denotes empathy as a sense of similarity between the feelings an individual experiences and those expressed by others. There are quite a few systems that enable the collaborators to share physiological cues [5, 11, 13, 21]. Most of these systems shared heart rates to enhance various collaboration experiences. Some

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*e-mail: prasanth.sasikumar.psk@gmail.com
†e-mail: yspai1412@gmail.com
‡e-mail: huidong.bai@auckland.ac.nz
§e-mail: mark.billinghurst@auckland.ac.nz

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researchers have looked at manipulating the heart rate information to enhance social presence [9, 10].

Researchers have also looked into using Galvanic skin response (GSR) as an index of cognitive load [23], and various physiological cues like EEG have been used to enable adaptive training systems using VR technologies [8]. In our system, we combine these physiological cues to study the effect of sharing them in a collaborative setting.

3 SYSTEM IMPLEMENTATION

Inspired by existing collaborations systems like Spatial and Mozilla Hubs, we developed a live remote collaboration system that is open-source and modular.

Figure 2 shows an overview of our system. Participants on both side wear the VR headset and shimmer sensor. Virtual objects including the engine, tools, and surrounding environment are aligned and synced in all virtual space, which allows users to feel that they are co-located in a shared MR space, the same as in face-to-face communication. We connected all devices to the same private network for fast data exchange.

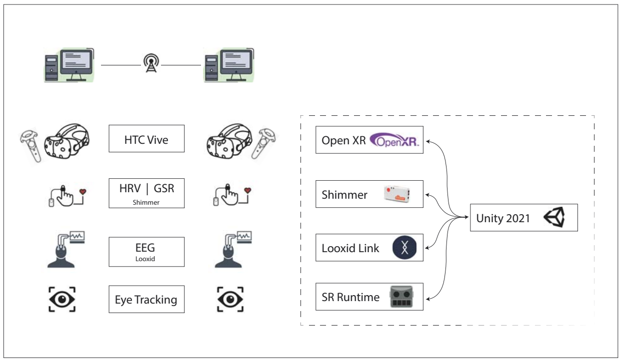

Figure 2: System overview - Hardware implementation on the right side and software components on the left

The prototype was built with Unity 3D Game Engine (2021.1.20f1) and tested on two HTC Vive pro eye (https://www.vive.com/nz/product/vive-pro-eye/overview/) VR headsets tethered to two Windows 10 computers. A shimmer 3 sensor was used to calculate the GSR (for cognitive load) and Heart rate. A Looxid add-on attachment was mounted to both the Vive headsets to collect the EEG data, providing the attention values of the collaborators. The implementation can be broken down into three individual independent components: 1) Remote collaboration system, 2) Physiological sensing manager, and 3) Virtual environment. These components are discussed in detail in the following sections.

3.1 Remote collaboration system

In general, networked VR systems are concerned with sharing consistent virtual worlds in real-time. There are various networking strategies behind remote collaboration systems [24, 25, 28]. We had considered developing a similar system to [15] using photon and [2] using TCP-IP connection.

After considering a wide variety of platforms and tool kits [14, 19, 29],we chose to use Ubiq [12] for networking as it was easy to learn, open source and transparent. Ubiq also provided a plethora of core functionality for social virtual reality such as connection management, voice and avatars, etc. Though Ubiq supports networked system over the internet, we created a local server for optimum bandwidth.

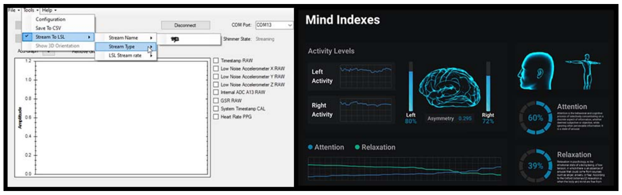
COM Port: COM13
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Figure 3: We created a standalone application to collect data from shimmer3 sensor via Bluetooth and stream the data to unity through LSL [18]. On the right side, Looxid link unity plugin adapted to work with OpenXR to collect the attention data from EEG.

3.2 Physiological Sensing Manager

To enable a framework that supports multiple physiological sensors to be integrated seamlessly, we created a few helper classes to manage physiological data. For the sake of this study, we implemented three streaming units - Heart rate, GSR and attention.

3.3 Virtual Environment

Prasanth et al [22] used volumetric playback to enhance the training experience in a Mixed Reality system. Inspired from this, we used a virtual engine with more than 50 individual parts that can be assembled or disassembled to simulate working on a real engine. Replica of a workshop with the engine mounted on an engine stand was created to enhance realism as shown in figure 4. Tools to work on the engine are placed around the workshop area. During the study, collaborators would follow the instruction prompt and work on the engine with the corresponding tool.

4 SYSTEM EVALUATION

In our study, we plan to use sharing heart rate without any other physiological cues as our control condition and the heart rate plus other physiological cues as the comparison. In this case, our primary independent variable would be the type of physiological cues that were shared between the collaborators, with four collaborative conditions:

- Heart rate (Base Condition)
- HR + Cognitive Load
- HR + Attention
- All

In the user study, we would be interested to investigate the following two research questions: 1) How does the sharing of physiological cues between remote users affect collaboration in a VR remote collaboration interface? 2) What are the benefits of mixing hear-rate, cognitive load and attention for VR remote collaboration compared with using each cue alone? Our research hypotheses are:

- Hypothesis I - Knowing the physiological cues of the participant enhances the performance of the remote collaboration system.
- Hypothesis II - Knowing the physiological cues of the participant enhances the co-presence of the remote collaboration system.
- Hypothesis III - Knowing the physiological cues of the participant enhances the immersion of the remote collaboration system.

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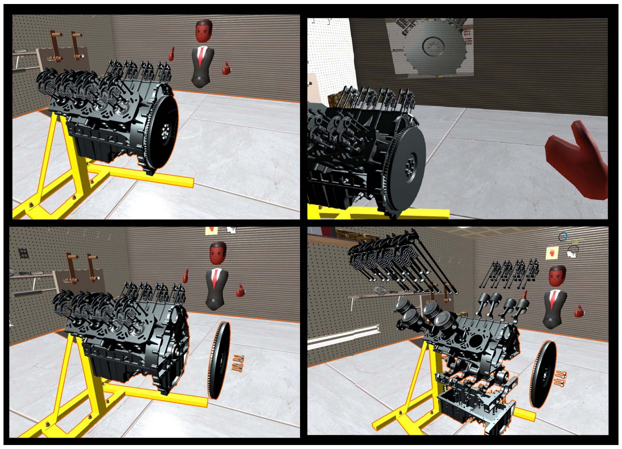

Figure 4: Tasks, clockwise from top, the engine assembly before operation. b) instruction on which part to remove. C) the corresponding part removed. d) Engine with components taken apart.

4.1 Experiment Procedure

The experiment would begin with the participants signing a consent form, answering demographic questions, and describing their experience with VR/AR. Participants would then be introduced to a short course on navigating in the Virtual space and the tasks. They would then wear the shimmer sensor and wear the VR headset.

Prior to be beginning of the experiment, the participants would stare at a black screen for a minute, then do a one back and then two back tests. This is to measure the average value of low, medium and high cognitive load respectively.

From a set of tasks, system chooses a random subset of 12 tasks(four easy, four medium and four hard) to be performed in each condition. After each condition, the participants would answer the questionnaire in VR. This is to preserve the contact of EEG electrodes and GSR sensors. At the end of the last condition, participants would take off their headset to rank the conditions and provide feedback.

Though we have implemented sharing of eye gaze, we would limit that to logging eye gaze data to evaluate it post study with the physiological cues. This is due to the fact that eye gaze is more of a natural user centric cue than a physiological one. We would be interested to know the co-relation(if any) between the conditions.

4.2 Measurements

We plan to use a within-subject design between four trials of different cue conditions, as described above. For each pair of participants, one would be providing the other with the task information for half the tasks and swap roles after, without swapping for each condition as a between group design. We chose this design because it reduced the time for the study, participants would feel less tired or bored, and it would alleviate the learning effect to some extent.

We would collect both objective and subjective measures from each condition. The time for completing the tasks would be recorded in a system log file to objectively measure task performance. At the end of each trial, the participants would be asked to complete subjective questionnaires(from within the VR environment). We would use the following questionnaires:

- NASA TLX [17]
- SUS [4]
- NMM Social Presence Questionnaire [16]
- Ranking

5 USE CASES

Teaching and training. This includes networked and social VR. By creating a framework that is easy to learn, transparent, and integrate well with familiar tools and existing hardware. Knowing the physiological cues of the students would be beneficial to the tutor tailor the learning experience.

Support Research in VR. Advantage of having a framework with plug and play extensions for physiological sensors is that it would become easier for researchers to measure empathy in remote collaboration. It would also enable testing of physiological sensors easier in a collaborative setting so researchers can work on their experiment rather than the platform.

Psychology and counseling. Therapy using Virtual Reality has been proven to Enhance Treatment of Anxiety Disorders [3]. The ability to know the physiological cues of the patient during therapy would open new possibilities for research and also to enhance therapy.

6 CONCLUSION

We presented a collaborative VR solution that can be integrates physiological sensing to enhance empathic collaboration. With PSCVR, users can collaborative and work together in a way that might not be possible in the physical world. We broke down the system into three parts(remote collaboration system, Physiological sensing manager, and virtual environment) and described the motivation behind the development. We discuss features, modes of interaction, our findings from development, and plans for further development and user testing.

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