A Quality of Experience Evaluation System and Research Challenges for Networked Virtual Reality-based Teleoperation Applications

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ABSTRACT

Teleoperation applications are designed to assist humans in operating complex mechanical systems. Interfaces to teleoperation systems have always been challenging. Recently the potential of virtual reality (VR) has been a topic of interest, particularly with the availability of head mounted displays and interaction controller devices. As a result, research into the viability of VR as a technology to support remote operation and improved human machine interaction has emerged. It is assumed that VR will offer a user more immersive and natural experiences when operating a virtual representation of a mechanical system. To achieve this, there are a number of research challenges that need to be addressed. In this short paper, we introduce and discuss key challenges for VR-based teleoperation systems. Since the key focus of our work is understand user quality of experience (QoE) of VR-based teleoperation applications, the design and implementation of an implicit and explicit QoE Evaluation system is presented.

CCS CONCEPTS

• Human-centered computing → Virtual reality

KEYWORDS

Quality of Experience, Virtual Reality, Networks, Network Delay, Remote Operation, Cyber Physical Systems, Physiological Metrics

1 Introduction

Teleoperation based applications refers to the use of a computer-based interface that allows a human to control or issue commands to a physical mechanical unit. Research has been conducted in the area of teleoperation to demonstrate the efficacy of using human remotely controlled systems to complete tasks of varying complexity. While a computer terminal is the most common method of interaction in an industrial environment between the operator and the target system, new alternative, and more immersive, methods can be considered as potential interfaces for teleoperation.

Virtual reality (VR) is one alternative technology for teleoperation. However, it is important to understand VR from a quality of experience (QoE) perspective in an industrial environment. QoE can be defined as “the degree of delight or annoyance of a person whose experience involves the application, service or system in question” [1]. QoE has emerged as suitable vehicle for the research community to measure user engagement with novel technologies. Though typically used in the area of telecommunications, studies into other useful areas of research have been undertaken including that of immersive technologies such as virtual and augmented reality [2]. Of particular interest from a QoE perspective in a teleoperation-based industrial environment is the impact of network delay and latency. A user’s QoE can be impacted negatively by increasing levels of network delay, as seen in other domains such as gaming and multimedia [3]. While network delay is understood to negatively impact user experience, the degree to which it impacts a VR-based industrial environment application has not been explored. This paper presents research challenges for VR based Teleoperation and a QoE system to understand the impact of network delay on user QoE in a VR-based teleoperation environment.

2 Research Challenges

2.1 Digital Twin & Teleoperation

One of the challenges involved in this research was to appropriately design a simulation that accurately reflected what would be expected of a teleoperation task. Teleoperation naturally fits as a use case for Digital Twin [4] applications, where a physical mechanical process is mapped to a virtual twin, an important aspect of the emerging Industry 4.0. For this reason, a simulation that reflected the Digital Twin paradigm was created in this work. A user-controlled industrial environment was developed where the user could operate a virtual representation of a machine that would give the impression of operating on a real-life version of that same machine.

2.2 Virtual Reality Interaction

Virtual Reality teleoperation is a technology that is heavily influenced by human factors. Issues such as cyber-sickness and telepresence have significant impact on how well a human adapts to using a VR application [5][6]. Other factors include the effect of visual fatigue of VR hardware on humans [7], as well as the acceptance of naturalistic control schemes [8]. All of these influence the human perception of VR environments. An understanding of how these factors impact human perception is crucial to improving user QoE in a VR environment.

2.3 QoE Evaluation

Research on how to evaluate user QoE from implicit and explicit perspectives is an active topic across a broad range of application domains. While different frameworks have been proposed for QoE evaluation, there is a defined set of practices set out in [9] for researchers undertaking studies in the area of QoE for multimedia visual-audio systems. These involve the use of subjective metric capture, using surveys or questionnaires, to formulate a mean opinion score (MOS), which is used to measure overall user QoE. In addition to explicit subjective QoE metrics, implicit objective QoE metrics are widely used. Biometric signal measurement, gathered using non-invasive devices, is an example of such implicit metrics. Both explicit and implicit QoE metrics are used in the work presented here.

2.4 Network Challenges for VR-based Teleoperation

Comprehensive networked capabilities are a fundamental requirement to support Industry 4.0 and its related technologies. Teleoperation applications require access to these networks. While network-centric research into this aspect of teleoperation applications does exist [10], very little in the way of human-focused studies have been carried out. Network delay, loss, jitter and synchronization can have a negative impact on human interaction [11][12]. These types of network characteristics in other real-time applications can heavily impact the usability and uptake of a technology [13]. As such it is necessary to understand from a QoE perspective, how humans respond to network characteristics in an immersive environment, with focus on user perception of system usability. Network characteristics need to be studied individually and collectively to understand their effect on VR-based usability and utility.

3 Proposed Framework and QoE Assessment Methodology

In this section the proposed VR-based teleoperation framework and QoE assessment methodology are presented.

3.1 Virtual Reality Device and Environment

The Virtual Reality device selected for use in this study was the HTC VIVE [14]. The VIVE uses an internal AMOLED (active-matrix organic light-emitting diode) screen with a resolution of 1080 x 1200px per eye (totaling 2160 x 2400 pixels). This is paired with a field of view of 110° degrees, which is close to the average human FOV (roughly 120°). The VIVE is tracked using two wall- or stand-mounted lighthouses, which serve to act as a motion tracking system capable of projecting to a 4.6 x 4.6 m^2 area. Users interact with the elements in the virtual environment using native controllers called wands. The output of these wands in terms of click frequency and total clicks over time were captured and recorded as an indicator of user frustration. The Virtual Reality environment was developed using the Unity game engine [15] (Version 2017.4.3). Within the environment the user is tasked to operate a virtual representation of a Fanuc Roboshot Injection Moulding a-S130ia (see Fig. 1) [16], designed with Digital Twin practices in mind. This machine was chosen as it both fulfilled the requirements of a physical system capable of the design principles required for Industry 4.0. When interacting with the VR based Fanuc Injection moulding machine, users are guided through operation of the Fanuc via instructions provided within the VR environment.

3.2 Network delay simulation

A major challenge in the development of the QoE capture framework for VR-based teleoperation was the simulation and control of variables, such as delay and jitter, in the networked virtual environment. The method used involved hosting the VR application on a server supplied by Photon [17] as per Fig. 2. The system is sheltered from the influences of a wider network, thus enabling the tight control of the variables under evaluation. A toolkit native to the Windows operating system was used [18], which allows for a great degree of control over traffic on specific local connections. Network delay was injected between the localized server and the client running the networked virtual reality environment. This resulted in a delay of interaction in specific elements within the virtual environment, without the need to account for jitter or packet loss. The delay step sizes have been tested in increments of one second: no delay, 1s and 2s.

3.3 Implicit & Objective Metrics

Throughout the experiment, objective heart rate and EDA physiological metrics are captured, using the Empatica E4 [19], to understand the user state as they experienced the VR-based

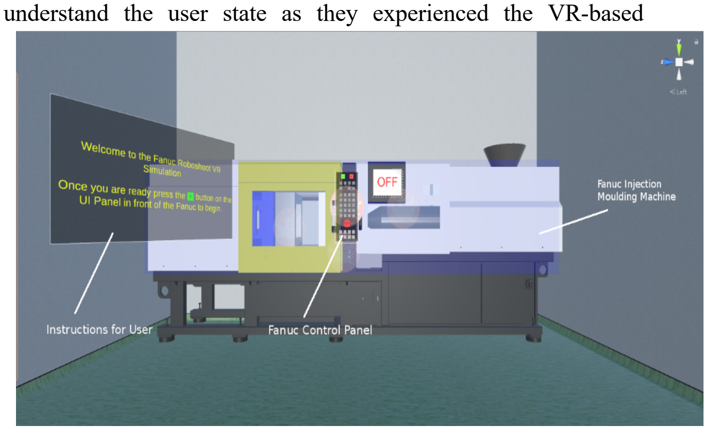

Figure 1: Image of the presented virtual environment

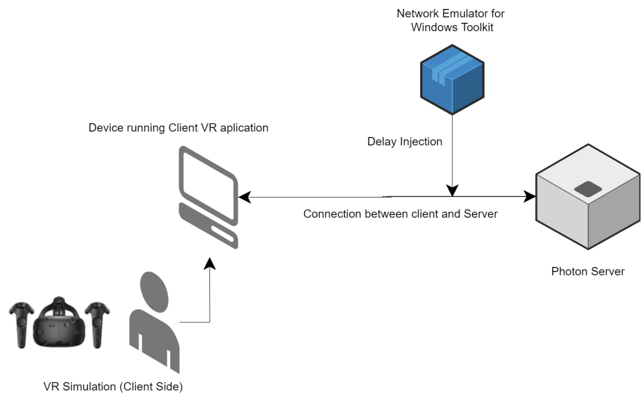

Figure 2: Overview of Network Framework

teleoperation system. The proposed QoE framework also captures eye tracking data, using a modified version of the HTC Vive developed by Tobii [20]. Eye tracking data has been shown in previous studies to be an indicator of cognitive load and a prediction method for quality assessments [21]. The Tobii HMD allows for discrete, non-invasive tracking of user gaze and head. The advantage of this over more established methods of eye tracking (cameras, head worn devices) is that the eye tracking components are effectively hidden from the user, eliminating potential biases of discomfort. A framework to construct 3D heatmaps to display eye movement across the virtual environment was developed as a method of visualization. This framework used outputs from the Tobii SDK to project a *ray* in the virtual environment corresponding to a user's gaze when wearing the HMD. This gaze can be detected by raycast sensitive objects hidden from the subject's view. These objects are linked to a shader, controlled by the graphics processing tools within Unity, and from these we can develop heatmaps corresponding to the position and frequency of a user's gaze within a specified area.

4 Conclusion

In this paper, research challenges for a VR-based teleoperation system were presented. A system was developed along with a framework to capture QoE metrics. The QoE capture framework, the main focus of this work, tracks and captures multiple in-environment variables, such as user interactions and controller events, heart rate, electrodermal activity and eye tracking information. An eye data processing system, capable of developing 3D heatmaps within the virtual environment, was developed allowing an understanding of user attention focus and gaze. The VR-based teleoperation system supports the control of various network characteristics, enabling an evaluation of how users react to network delay within a virtual reality environment. The contribution of this QoE evaluation method will be useful for predicting user-perceived usability and acceptance for teleoperation-based immersive applications,

REFERENCES

[1] Möller, S. and Raake, A. eds., 2014. Quality of experience: advanced concepts, applications and methods. Springer.

[2] Keighrey, C., Flynn, R., Murray, S., Brennan, S. and Murray, N., 2017, October. Comparing User QoE via Physiological and Interaction Measurements of Immersive AR and VR Speech and Language Therapy Applications. In Proceedings of the on Thematic Workshops of ACM Multimedia 2017 (pp. 485-492). ACM.

[3] Jarschel, Michael, et al. "An evaluation of QoE in cloud gaming based on subjective tests." 2011 Fifth International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing. IEEE, 2011.

[4] Rosen, Roland, et al. "About the importance of autonomy and digital twins for the future of manufacturing." IFAC-PapersOnLine 48.3 (2015): 567-572.

[5] Schuemie, Martijn J., et al. "Research on presence in virtual reality: A survey." CyberPsychology & Behavior 4.2 (2001): 183-201.

[6] Davis, Simon, Keith Nesbitt, and Eugene Nalivaiko. "Comparing the onset of cybersickness using the Oculus Rift and two virtual roller coasters." Proceedings of the 11th Australasian Conference on Interactive Entertainment (IE 2015). Vol. 27. 2015.

[7] Ukai, Kazuhiko, and Peter A. Howarth. "Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations." *Displays* 29.2 (2008): 106-116.

[8] Martel, Erin, and Kasia Muldner. "Controlling VR games: control schemes and the player experience." Entertainment computing 21 (2017): 19-31.

[9] Recommendation ITU-T P.910, Subjective video quality assessment methods for multimedia applications. ITU-T Study Group 12*, 2008.*Hoβfeld, Tobias, Raimund Schatz, and Sebastian Egger. "SOS: The MOS is not enough!." 2011 Third International Workshop on Quality of Multimedia Experience. IEEE, 2011.

[10] Sheridan, Thomas B. "Space teleoperation through time delay: Review and prognosis." IEEE Transactions on robotics and Automation 9.5 (1993): 592-606.

[11] Montagud, Mario, et al. "Inter-destination multimedia synchronization: schemes, use cases and standardization." Multimedia systems 18.6 (2012): 459-482.

[12] Ries, Michal, Philipp Svoboda, and Markus Rupp. "Empirical study of subjective quality for massive multiplayer games." 2008 15th International Conference on Systems, Signals and Image Processing. IEEE, 2008.

[13] Gutwin, Carl. "The effects of network delays on group work in real-time groupware." ECSCW 2001. Springer, Dordrecht, 2001.

[14] "VIVE™ | Discover Virtual Reality Beyond Imagination," HTC, [Online]. Available: https://www.vive.com/eu/. [Accessed 28 03 2019].

[15] "Unity", Unity [Online]. Available: https://unity3d.com [Accessed 28 03 2019].

[16] "FANUC ROBOSHOT electrical injection moulding machine", Fanuc, [Online]. Available: https://www.fanuc.eu/dk/en/roboshot/. [Accessed 28 03 2019].

[17] "Photon Unity 3D Networking Framework SDKs and Game Backend | Photon Engine", Photon, [Online]. Available: https://www.photonengine.com/en/pun [Accessed 28 03 2019].

[18] "Network Emulator Toolkit The virtual world of Marc O Polo" Network Emulator for Windows Toolkit, Available: https://blog.mrpol.nl/2010/01/14/network-emulator-toolkit/ [Accessed 03 04 2019]

[19] "Real-time physiological signals | E4 EDA/GSR sensor – Empatica", Empatica, [Online]. Available: https://www.empatica.com/en-gb/research/e4/ [Accessed 28 03 2019].

[20] "Eye tracking technology for research – Tobii Pro", Tobii, [Online]. Available: https://www.tobiipro.com/ [Accessed 28 03 2019].

[21] Arndt, Sebastian, et al. "Using eye-tracking and correlates of brain activity to predict quality scores." 2014 Sixth International Workshop on Quality of Multimedia Experience (QoMEX). IEEE, 2014.