Modular Immersive Virtual Reality System for the Analysis of Emotional Reactivity

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Abstract — We propose a Modular Immersive Virtual Reality System that can be used towards the development of Immersive Virtual Environments (IVE) with variable sensor requirements that, in turn, are intended to be used to support experiments related to Virtual Exposure Therapy, Physical Therapy, and Rehabilitation. Specifically, by utilizing the Unity game engine and modular sensor architecture, the proposed system is aimed to support the development of virtual environments synchronized with multi-sensor input and output. Based on the intended usage, our system can be used to record user responses via built-in surveys and to accommodate for extensive robotics and sensor requirements focusing on synchronous user interaction and input.

Keywords—Virtual Reality; Body Ownership; Emotional Reactivity; Immersion; Virtual Environments; Data Collection

I. INTRODUCTION

A perception of being physically present in a non-physical (or virtual) world is known as an immersion into virtual reality created by a computer-based system of images, sounds and/or other stimuli that provides a user with an engrossing experience in an imitated environment. Healthcare has adopted various Immersive Virtual Environment Systems (IVES) to generate simulated environments for medical skills training, surgery imitation, and phobia treatment in a safe environment without risk of physical harm to patients. Recently, the areas of application of IVES as a therapeutic tool have been extended to exposure therapy, counseling, and physical rehabilitation. For example, when used for exposure therapy virtual reality systems allow patients to be safely immersed in a Virtual Environment simulated in response to the area of patient’s concern. When used for counseling, IVEs can be used to simulate human contact interaction over long distances to the benefit of patients. When used for physical therapy, IVEs can help to simulate proper muscular motion and also to provide direct feedback of patient rehabilitative efforts. Although application of IVES offers a great benefit to healthcare, the design and development of particular virtual environment varies greatly depending on the needs and purpose of the field in which the system should be deployed. Unlike existing systems, the proposed Modular Immersive Virtual Reality System (MIVRS) serves as a general development platform for the IVEs that can support a wide range of options including system-user interaction and sensor measurement input and output.

A. Ownership in Virtual Reality

Immersive Virtual Environment Systems rely on the concept of body ownership as a measure of immersion in Virtual Environments (VEs). Body ownership is a concept of the brain reaction of a participant to stimuli in relationship to a substitute body, or a player’s virtual body within a VE, in a manner similar to that of its response to the participant’s true body.

The concept of body ownership originated as an extension of a perceptual illusion known as the Rubber Hand Illusion (RHI). In the RHI, a rubber hand (or virtual hand) is placed next to a
participant’s true hand, and the participant’s true hand is covered from view. An experimenter then touches the participant’s hidden true hand and the visible rubber hand synchronously. This simultaneous visuo-tactile stimulation will cause the participant’s brain to respond to threats and stimuli to the rubber hand in a similar manner as threats to the participant’s true hand. When this “ownership” is taken over the rubber hand, the body will experience various physiological phenomena such as changes in histamine and temperature regulation in the true hand [4].

In recent years, through the increased availability of Head-Mounted-Displays (HMDs) and VEs, this perceptual illusion has been expanded to encompass an entire body, namely the body swapping illusion. Using the body swapping illusion, many immersive VR systems grant a test participant ownership over an entire virtual body [10],[12]. Petkova and Ehrsson implemented an early application of the body swapping illusion wherein they had participants swap bodies with stationary mannequins. The body swapping illusion was performed by having the participant use a head-mounted display that saw from the vantage point of a camera mounted on the head of the target mannequin [9].

The most commonly used measure for immersion in VEs is a measure of the response to threat via skin conductance. When a participant has taken ownership over a virtual body, the participant will express a strong threat response towards threats to the virtual body, which can be observed via a sudden change in the participant’s skin conductivity [4]. This was well illustrated during an experiment in which Petkova and Ehrsson had participants swap bodies with the body of one of the experimenters while maintaining vision of their true body. After performing the body swapping illusion on the participants, Petkova and Ehrsson found consistently higher threat response values for the body the participant had ownership over when compared against the response to threats against the participant’s true body [8]. Other existing methods can also be used to measure body ownership, however many of these methods, while focusing on accuracy of measurements result in either reducing the participant’s level of ownership (e.g. cross modal congruency testing) or in the time necessary for testing (e.g. measuring changes in temperature regulation) [7], [12].

Virtual reality when applied to exposure therapy, known as virtual exposure therapy (VET), involves the development of IVEs to induce and record the emotional state of the participants. Participants’ emotions can be measured on either discrete or continuous scales. The discrete model considers emotions that have distinctive discrete states, namely happiness, sadness, anger, excitement, etc. The continuous model for emotion places the discrete emotions on a two-dimensional arousal-valence plane, where physiological arousal is a measure of focus and attentiveness, and valence is a measure of positivity and/or negativity. There are two methods that are used when measuring a participant’s emotional reactivity to an event. Measuring a participant’s emotional reactivity to an event is done with either a self-survey or through physiological sensors. For either model (discrete or continuous), self-reported questionnaires provide the most accurate measurements of a participant’s emotional state at a given moment. In the continuous model, physiological sensors can be used to provide insight into the change of a participant’s emotional state. Physiological sensors, based on their placement, provide an indication of changes in a participant’s arousal and/or valence, which can be correlated with the participant’s questionnaire responses. The most commonly used physiological signals corresponding to arousal are skin conductance and changes in heart rate. The signal that most accurately measures valence is a level of muscle tension in the jaw [1], [6].

8. Modern Virtual Reality Systems

IVE systems developed for counseling and exposure therapy usually focus on building detailed experimental environments and collecting self-reported user responses (surveys) to these environments. Typically, these IVE systems can create and control different virtual scenarios and record the participant’s emotional response to these
scenarios by providing participants with particular physical viewpoints (targets) and perspectives and/or placing participants into an environment that is expected to cause a particular emotional reaction. In general, when used for counseling and exposure therapy, such IVE systems measure the response of a passive user to environmental stimuli and often do not require any additional equipment for a user to interact with the VEs [8]. For example in a study on drumming within an IVE, Kilteni and Bergstrom had participants undergo an identical task of drumming with differing virtual bodies, and noted a marked behavioral difference dependent on the racial characteristics of the virtual body [5].

When IVESs are used for physical therapy and rehabilitation, there is a need to incorporate physiological sensors in addition to robotics that are to be used for system-user interaction. When the system is aimed at maintaining ownership between the user’s virtual body in relationship to the robotics and sensors, the system must respond in a time under 150 ms, which is considered to be the maximum time for which a response to an action can occur for the brain to consider the action to be self driven [3],[11], [13]. IVEs for physical therapy and rehabilitation must allow for a high degree of system-user interaction. Due to the focus on high responsive synchronous system-user interaction of such systems, IVESs that are used for physical therapy and rehabilitation tend to be high cost and designed around specialized robotics interfaces [2].

The main focus of this project is on the development of a MIVRS that emphasizes the analysis of emotional reactivity to VEs while potentially allowing for participant interaction with the VEs. Such system must support the integration of pre-specified VEs with physiological sensors to measure changes in the user’s physical and emotional state in relationship to the state of the VE. This platform should also support the equipment necessary for a user interaction with the VE and a survey system necessary for a self-reported data collection. It should also allow for additional equipment to be attached to the system as needed.

The rest of the paper is organized as follows. A brief description of the equipment used for the proposed system. Followed by the general architecture of the proposed system and the modular sensor input design.

II. System Architecture

A. Equipment

Our system is designed to work with the Unity 5 Game Engine and utilizes Unity’s VR library allowing any modern consumer level HMD to be used in the system. For the series of experiments currently conducted, the HMD in use is an Oculus Rift DK2. The physiological sensors required for our current projects are Galvanic Skin Response (GSR) and Blood Volume Pulse (BVP) sensors. Sensor readings are collected by an Arduino Uno board that communicates with the Unity workstation via a wired USB connection.

B. System Overview

The purpose of the proposed system is to immerse a participant in a VE as dictated by a Scenario. The Scenario is a script that defines the VE and a sequence of steps to be completed by a participant. Following a pre-selected Scenario, multiple Events can occur at various times and locations in the VE. An Event is considered to be any change in the VE that may result in a stimulus response from a participant. In our proposed system the Event can be either a Scenario (i.e., a System) Event or a User Event. A Scenario Event is an event that is driven by the pre-selected Scenario. The participant does not have a direct control over occurrence of a Scenario Event. A User Event is an event that is triggered by an action performed by the participant. For example, according to one of our System Scenarios, when the Event happens a predefined questionnaire is presented to the participant and the participant can provide responses without leaving virtual environment. Following the Scenario the participant may have their physiological state recorded via external sensors if external sensors are required as part of the experiment setup.
C. System Architecture

The proposed IVES, schematically represented in Figure 1, consists of four components responsible for external sensor communication (Sensor Interface), event triggers (Event Interface), internal monitoring and decision-making (Manager), and Input-Output.

The centralized Experiment Manager (ExManager) interprets incoming data and propagates subsequent decisions throughout the VE. All sensors, questionnaires, and event components included in the experiment must be registered through the Experiment Manager during initialization. On launch, the ExManager generates a random ID for the experiment session to be used as the non-identifiable key to record data from the session. When external sensors are registered through the ExManager they connect to and have a data queue established on the Sensor Interface. All incoming data coming in over an external sensor are sent to the sensor’s data queue on the Sensor Interface. All components during the experiment to which an event is attached (i.e. event components), must register themselves with the Experiment Manager via an event ID defined in an external event database. Interactive information is stored and presented to the participant through the IO Interface. Surveys for an experiment are registered through the ExManager on initialization and stored in a hashtable.

D. Sensor Component Modularity

The generic nature of the Monitor and Sensor Interface Components allows for sensors to be added with no modification to the underlying system architecture. Sensors are registered to the ExManager by providing the serial port for the Serial Interface to poll for the sensor’s data. Examples of two disparate equipment setups are shown in Figures 2(a) & 2(b). The experiment for Figure 2(a) uses a Hall Effect sensor to match movement patterns of a physical bike in a VE. The experiment for Figure 2(b) is lightweight and has no requirements other than the base physiological sensors used to measure immersion (skin conductance) and a game controller. Both experiments run from the same underlying framework with specifications done in the Unity VE as needed.
III. DATA COLLECTION

A. Data Description

The data collected by the ExManager, as demonstrated in Table 1, consists of the timestamp, avatar position, avatar orientation, primary camera orientation, sensor data, and event occurrence identifiers. Event specific information is stored separately.

Table 1- Data Frame Representation

<table>
<thead>
<tr>
<th>Sample Participant</th>
<th>ID</th>
<th>146</th>
<th>146</th>
</tr>
</thead>
<tbody>
<tr>
<td>time</td>
<td>2</td>
<td>2055</td>
<td></td>
</tr>
<tr>
<td>Po(x,y,z)</td>
<td>(3.00,2.33,3.56)</td>
<td>(188.75,34,1.56)</td>
<td></td>
</tr>
<tr>
<td>Orientation(x,y,z,w)</td>
<td>(0.31,0.87,0.94,0.65)</td>
<td>(0.31,0.87,0.94,0.65)</td>
<td></td>
</tr>
<tr>
<td>CameraOrientation(x,y,z,w)</td>
<td>(0.65,1.34,1.94,0.12)</td>
<td>(1.12,0.23,0.24,1.38)</td>
<td></td>
</tr>
<tr>
<td>Sensor 1</td>
<td>35</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Sensor n</td>
<td>640</td>
<td>635</td>
<td></td>
</tr>
<tr>
<td>Event 1</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Event n</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

B. Frame to Frame

The main update thread of the ExManager is called at the frame rate of the VE. In the current iteration of our system, the VE is rendered at a frame rate of 75Hz, the required frame rate for the Oculus Rift DK2. The ExManager’s main thread extracts the participant’s position and orientation data from the VE and sends this information to the Monitor.

Upon receiving the participant’s positional data, the monitor requests all sensor data recorded over the Sensor Interface since the previous frame was received. The Monitor interpolates the sensor data from the Sensor Interface data queues to back fit the global sampling rate specified by the ExManager. After the scenario positional and external sensor data have been interpolated to the specified frame rate (Figures 3 and Figure 4), the data consisting of the scenario state is sent back to the ExManager.

While the system design allows for alternate interpolation methods for the sensor and positional data, linear interpolation is the used by default. Natively, the system takes in a sensor’s raw data. When filtering is necessary, it can be performed during the data interpolation, however that is beyond the scope of this paper.

Upon receiving the latest data packet from the Monitor, the ExManager checks that an event has not occurred since the previous frame occurred. If no event has occurred, the ExManager sends the data packet to the file writer to record the most recent data to the participant’s experiment repository.

C. On-Event Trigger

When an event occurs, the corresponding event component alerts the ExManager. The ExManager upon receiving an event alert tags the upcoming frame with a flag for the event that occurred, as shown in Figure 5. If the event triggered requires a change in the VE, the ExManager sends a notification to the linked event component. If the event triggered has a request for user feedback, then the specified survey/questionnaire is provided to the participant. Once the survey has been completed, the results are to be written via the file writer to the participant’s experiment repository.

![Figure 2 - Two separate experiments developed on the proposed system. (a) A bike riding experiment with a Hall Effect sensor incorporated for synchronized wheel movements, (b) A seated multi-perspective experiment incorporating a game controller for user input](image)
IV. CONCLUSION

The MIVRS proposed in this paper meets the requirements for experiments involving the analysis of Emotional Reactivity within a VE. Employing the VR libraries of the Unity game engine to ensure support for current consumer level HMD, eases the development of the VE by eliminating the development of custom HMD interfaces and libraries. The modular design of the sensor system allows for the proposed framework to be used for the development of a wide range of VEs with minimal configuration and reduces the need to redevelop the system based on the hardware needs of the experiment.

REFERENCES


