Excite-O-Meter: an Open-Source Unity Plugin to Analyze Heart Activity and Movement Trajectories in Custom VR Environments

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Abstract

This article explains the new features of the Excite-O-Meter, an open-source tool that enables the collection of bodily data, real-time feature extraction, and post-session data visualization in any custom VR environment developed in Unity. Besides analyzing heart activity, the tool supports now multidimensional time series to study motion trajectories in VR. The paper presents the main functionalities and discusses the relevance of the tool for behavioral and psychophysiological research.

Index Terms: Human-centered computingInteractive systems and tools; Human-centered computingVirtual reality; Computer systems organizationReal-time system architecture

1 Introduction

A primary goal of VR is to create relevant and engaging experiences. However, humans differ and do not experience VR content in the same way. How can we know what users find relevant and engaging? Collecting user ratings (e.g., about their current affective state) has disadvantages: Self reports require users to distract their attention from the experience itself (potentially interrupting immersion), they are typically non-continuous and thus have low sampling frequencies, and they are prone to biases (e.g., distortions when reporting in retrospect, in summary, or from a third-person perspective). Bodily (i.e., physiological) signals and movement data (e.g., head, limb, eye movement) are relatively unobtrusive and continuous measures, which can be analyzed to adapt and optimize VR content.

For "internal" bodily signals, one can use commercially available digital health sensors, such as chest straps to record cardiac activity. Data about head and some other bodily movements (e.g., controller/hand) are automatically recorded by VR systems. Other modalities (e.g., leg or eye movements) typically require additional hardware. Such "internal" and "external" body dynamics can be used to study the relationship between audiovisual stimuli and human behavior in controlled virtual scenarios. In addition, the construction of interactive VR environments is easier than ever before, for example with authoring software such as the game engine Unity [12]), which minimizes the technical knowledge required to design 3D environments and execute them in VR headsets.

Although game engines streamlined VR development, challenges remain to transform any virtual environment into a platform to study human behavior. For example, researchers or game developers could create custom VR environments with predefined stories and interactions. However, conducting behavioral analysis with participants or users demands time and technical knowledge to implement additional functionalities to connect external body sensors, continuously and reliably log data, and synchronize the stimuli and responses. Another option would be to acquire commercial licenses that facilitate these operations, but they might be expensive or incompatible with already developed VR applications.

The `Excite-O-Meter` [8] is an open-source software framework that solves these technical obstacles. It enhances any custom desktop VR application with extra functionalities for behavioral analysis; such as incorporating bodily data, extracting features in real-time, and conducting a post-session review of the user's interactions. The initial version of the tool supported unidimensional time series and was specifically designed to study the heartbeat-related (i.e., heart rate and heart rate variability, HRV) responses from people interacting with a VR application. The initial validation used cardiac information in a rule-based model to estimate the continuous "excitement level" elicited by a virtual environment. The tool has evolved, and the new features include better compatibility with the latest versions of Unity and, more importantly, support for multidimensional time-series data to analyze movement trajectories in VR.

Introducing movement analysis to the `Excite-O-Meter` is a substantial extension to the framework for three reasons. First, movement is a confounding variable for heart rate and HRV as movement intensity affects the user's physiological response levels, and analyzing only cardiac data could hamper other factors that can measure users' behavior (e.g., "excitement"). Therefore, jointly analyzing movement and heart activity allows for more valid behavioral metrics derived from multiple relevant data sources. Second, movement by itself is an indicator of psychological and emotional processes. Body expression has been found as informative as facial expressions in conveying affective states [4], and machine learning algorithms can recognize emotional states from body postures [5]. Lastly, VR systems contain sensors to accurately track motion from head and hands, becoming a suitable test bed to study relationships between human factors and movement trajectories [7].

Related work: Other tools also attempt to simplify behavioral research in VR, but they meet different requirements. For instance, commercial solutions[1] may be expensive and restrictive for smaller projects. A free package called UXF [1] can efficiently log Unity data but does not integrate external body sensors. Other software for experimental research, such as PsychoXR [2], can handle data from external sensors but cannot be integrated in Unity. Therefore, we consider the `Excite-O-Meter` a complementary - and for certain use cases preferable - solution that can alleviate technical obstacles, is easily adaptable to existing Unity projects, without requiring coding skills, and enables feature extraction and data visualization.

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[1] E.g., https://cognitive3d.com/ or https://silicolabs.ca/experimenter

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2 New features in the Excite-O-Meter

From the technical standpoint, the `Excite-O-Meter` [8] can incorporate bodily data from any sensors compatible with Lab Streaming Layer (LSL). The first version of the tool included heart activity measurements from the chest strap Polar H10. These cardiac data were all processed as unidimensional streams, which was insufficient for more complex sources (e.g., movement, brain activity).

Data collection: The major new feature is the support for multi-dimensional time series to track movement from any object in the Unity scene. The logged data include position in 3D space, and rotation in both quaternions and Euler representations (previous studies have shown that redundancy in the rotation representation could benefit behavioral analysis [9]). The data is processed using left-hand coordinate system, as in Unity. A convenient object to be tracked is the VR headset, which enables the analysis of user's field of view. In addition, the sampling frequency of the movement can be easily configured from the control panel, as depicted in Figure 1.

Feature extraction: This module calculates velocity and acceleration trajectories in real-time from the movement data stream. By default, the features are extracted using a buffer of three samples with one overlapping sample between calculations. The formulas for these features differ among rotation representations. Specifically, calculating velocity and acceleration for quaternions involve the Hamilton product between a quaternion $\mathbf{q}$ and its complex conjugate $\bar{\mathbf{q}}$ with inverted non-real dimensions (see equations 16-17 in [11]), whereas for Euler angles it accounts for the discontinuity caused by 0°=360° (see equation 17 in [3]). These and other cardiac features can be manually altered from a `json` file, to trigger the calculation by number of samples in the buffer or by a specific elapsed time.

Session data structure: A data collection session generates a folder with a predefined structure. The screenshots displaying the user's field of view are stored as `jpg` images in the folder `screenshots/`. Multiple time-series `csv` files are stored that correspond to raw heart activity (`hr`, `rri`), multidimensional movement trajectories (`movHeadset`), extracted features from heart (`RMSSD`, `SDNN`) and movement (`movHeadsetFeatures`). The file `_eventsAndMarkers.csv` may be used to segment the behavioral data according to the timestamp of each experimental stage (e.g., baseline, intervention, or breaks).

Offline data visualizer: This module lets any desktop VR application visualize synchronously the user's field of view, heart activity, and (e.g., headset) movement trajectories, as shown in Figure 2.

Unity compatibility: Finally, the tool was updated to guarantee compatibility with the game engine. The repository includes an example tested in Unity 2020.3 using Universal Rendering Pipeline (URP), the new input system (v1.2), and OpenXR runtime to assure execution in any desktop VR headset. The links at the end of the paper refer to the instructions and documentation for all features.

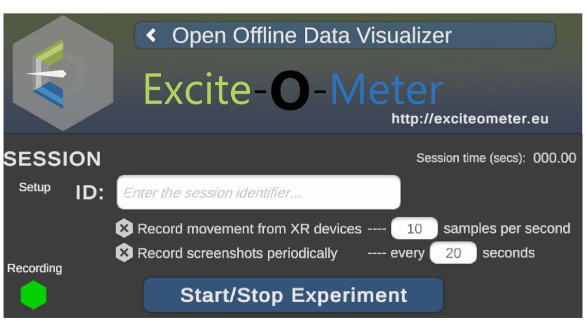

Figure 1: Control panel to configure the acquisition of behavioral data, choose whether movement data and screenshots should be captured. This panel superimposes the computer screen in any VR application.

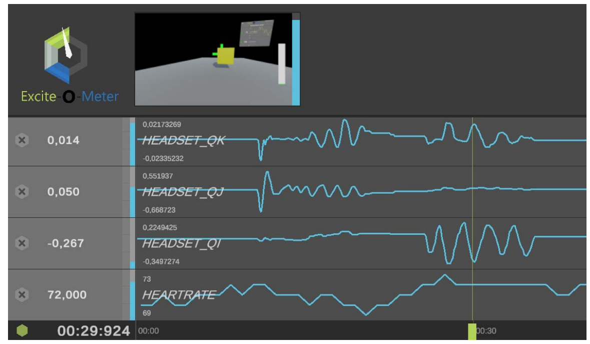

Figure 2: The tool displaying a user's field-of-view (screenshot), heart rate, and movement (quaternion) at second 30 of an example session.

3 Discussion

This paper outlined the new capabilities of the `Excite-O-Meter` to handle multidimensional time-series such as VR headset movement trajectories, in addition to the heart activity from wearables. In the future, more complex bodily time-series from the "internal" and "external" body can be integrated, such as brain activity or hand motion trajectories, respectively. Also, we envision this tool as a free and lively growing platform to facilitate empirical behavioral and psychophysiological experiments for researchers. Being an open-source project may also streamline the creation of larger public datasets to train machine-learning methods that help interpreting user behavior in VR [10]. Such an open-science ecosystem would ultimately also benefit VR-based solutions in healthcare, education, or training - augmenting them with computational systems that can estimate human cognitive and affective factors [6].

Availability: At `https://exciteometer.eu/` or open-source code at `https://github.com/luiseduve/exciteometer/`.

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