A QoE Evaluation of an Immersive Virtual Reality Autonomous Driving Experience

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Abstract— **The driver/passenger role in autonomous driving experiences is an important subject that is concerned with how these systems will interact and communicate with the human stakeholder. Even though self-driving technologies have made rapid progress in recent years, their success will depend on ethics, safe capabilities and user acceptance. The overall satisfaction resulting from the interaction between humans, these technologies and their evaluation in simulators can help industry to improve their design. Such evaluations can be based on user's perceived Quality of Experience (QoE). The impact of the quality features that compound VR environments is an important factor to understand. Sense of depth, texture quality and resolution are some examples that influence the perceived quality of the simulation and immersion levels. This demonstration promotes a VR autonomous driving experience in one street of Athlone, Ireland. The application will be presented in two different formats: photogrammetry, a technique that uses photos to provide realistic 3D content, and secondly non-photorealistic simulated environment. Further investigations will be carried out to understand factors that enable the highest immersive experience in autonomous vehicles considering feedback modalities between the car and its users.**

Keywords— Quality of Experience, Autonomous Vehicles, Virtual Reality, Perception, Physiological, Photogrammetry, Immersion.

I. INTRODUCTION

Self-driving cars have the potential to reduce accidents and congestion by minimizing human mistakes and streamlining the traffic flow [1]. Automated driving is already present in commercial vehicles in distinct degrees (from Society of Automotive Engineers (SAE) "level 1" to SAE "level 3" [2]). Fully automated cars (SAE "level 4" and SAE "level 5") are expected to be the twenty-first century revolution [3]. Although manufacturers claim to have the Autonomous Vehicle (AV) technology ready to be released, traffic safety, ethics, public acceptance and other user-centered concerns still need to be considered [17, 18, 19]. In the early stages of adoption, AV will need to share the streets with other road users (i.e. pedestrians, human-driven vehicles, cyclists, etc.) and depend on current infrastructure and its irregularities (i.e. holes on asphalt, unmarked roads, etc.) [4].

These challenges demand that testing AV is completed so that we understand the technology in terms of interactivity with these diverse types of road users. For this purpose, computational simulated environments stand as a solution for testing AV technologies. It is possible to perform AV tests and consider all possible events and communications that could occur between humans and the technology in real world [5]. Virtual Reality (VR) can be characterized by a set of instructional resources based on rendered graphics combined with other multimedia content that promotes interaction between the user and 3D environments [6]. VR can be used for gaming, but also educational and training purposes [7, 8]. VR is often used in scientific contexts to provide simulations and get replicable results [6].

The user of this type of application has a sense of presence with possibilities to explore the space and interact with elements of the environment [9]. The feeling of presence can be leveraged by using Head-Mounted-Displays (HMD). HMDs consist of monocular or binocular screens and a set of optic lenses that are worn on the user's head [10]. In the last decade, HMDs have become smaller and more accessible with high-resolution screens (i.e. OLED), enhanced sensing (e.g. integrated Inertial Measurement Units) and a wide community of developers [11]. As a result, highly immersive VR applications using HMD are being released and used in different contexts such as gaming, education, training [7][8] and industry 4.0 [12]. However, there is a need to evaluate the technologies, services and products related to VR and the relationship with the user that experiences the applications. Thus, a science that provides quality metrics from a user-centered perspective is demanded.

Quality of Experience (QoE) is such a science that can be applied to evaluate applications from the user's perspective. It is defined as "the degree of delight or annoyance of a person whose experiencing involves an application, service or system" [13]. QoE provides a mechanism to assess the correlation between the system, context and the user [14]. These entities have components called Influence Factors (IF) defined as "any characteristic of a user, system, service, application, or context whose actual state or setting may have influence on the Quality of Experience for the user" [13]. These can be seen in user's cognitive processing (IF described as Human Factors or HF) and in the content, media, stream quality and other device-related IFs, defining the System Influence Factors or SIF [16]. Moreover, the context that the user and the system are included is considered an IF and it can be decomposed into physical, temporal, social, economic, task and technical features. Consequently, IFs impact the overall perception of the application.

Figure 1- Overview of different setups and graphics quality used in driving simulators of related work [20,22,24,25].

Figure 2-Photogrammetry as a technique to create realistic 3D content based on photos.

In the AV domain, the vehicle's real-time feedback informs the user about its own decision making based on sensed external road events. Additionally, the effectiveness of the maneuvers performed and and safety topics illustrate the quality features that might impact the perceptual experience about AV by the user. VR systems can be used to simulate these real-world scenarios. This allows the collection of metrics on user perceived quality of AV experiences.

In this context, this work will present a demonstration of a VR Autonomous Driving experience. From traditional 3D modelling (i.e. using Blender [31]) to Photogrammetry, the experiences will have distinct graphical renderings that will be delivered in two demonstrations: with non-photorealistic and photorealistic elements. The perceived QoE in both modalities and will be used to quantify immersion. This system was built in order to solicit implicit responses (physiological metrics such as Heart Rate (HR), Electrodermal Activity (EDA), Eye Tracking and others)) and the scenario that provides the best QoE will be used to assess feedback modalities used in AV in future work.

II. RELATED WORK

In previous work, surveys have been conducted to understand the public acceptance of self-driving technologies [17, 18, 19] and simulations have been undertaken to assess the driver's performance in VR [20, 21, 22, 23, 24, 25]. Although substantial, there has been little attempt to validate the subjective data (i.e. post-application questionnaires) collected from the user's perceptions about the experience using objective and implicit QoE metrics. Generally speaking, these studies have not considered performance metrics or implicit metrics (e.g. eye gaze which could be particularly useful in an AV scenario).

A number of studies have focused on the impact of graphics quality comparing how different types of content presentation approaches influence user perceptual quality [32, 33]. In addition, certain studies have presented the simulation using 2D computer screens placed on a desk with a gaming steering wheel [25] whilst in other words, the simulation is conducted by the projection of the VR screen in front of a real car's cockpit [20, 22, 24].

Although a foundation with VR and non-VR driving simulators was established by [26], the differences in the user's physiological responses while driving a car were not assessed from a QoE perspective. Furthermore, there was no mechanism to tweak the quality features of the simulation to understand the relationship between immersion levels and rendered graphics in the same platform. These subjects are addressed in this demonstration considering the most immersive manner to provide VR content (using HMD).

III. METHODOLOGY

To build the environment, a low-cost state-of-the-art technique called Photogrammetry was used. This method uses photos taken from different angles to computationally define the sense of depth of the captured scene. To achieve this, videos from the real environment were collected of each building using a camera with 12mp resolution. The "takes" were recorded during the same time each day, with similar weather conditions to correctly capture the footage of the buildings. The 4K video was captured supported by a 3-DOF active gimbal to stabilize the camera. No compression was applied to the captured files. The images were then extracted from the video in synchronized frames (Fig. 2). Some of these frames were edited to erase pedestrians and cars.

The texture is also extracted from the pictures and the final result is a photorealistic 3D content. The software used to process these images was Meshroom [30] (offline-based image processing) and Autodesk Recap Photo [28] (cloud-based image processing). A total of 193 buildings were processed from images to a 3D object file. The outputs obtained from this process was called "high-polygon-based scenario" (grounded on the number of polygons that compounds each mesh) and provided the content to the photorealistic scenario for the AV evaluation.

A. *Non-Photorealistic vs Photorealistic meshes*

To assess the impact of photorealism over the proposed tests, the same scenario was built using non-photorealistic content. This type of quality can be observed in [20,22,24,25] where textures were applied over flat surfaces, like planes or boxes, and traditional 3D meshes were used. The non-photorealistic scenario is called in this demonstration "low-polygon-based scenario" and it has a low polygon count with no depth level on building structures and combined with the low texture quality. It delivers a scenario that looks more like a game. Autodesk Recap Photo and Meshroom allowed us to fine-tune the quality features that differentiates both scenarios with a process called "decimation". As a result, from a high-polygon mesh different levels of compression can be obtained until reaching a low-polygon model. The results between the highest and the lowest compressions can be seen in Fig. 3.

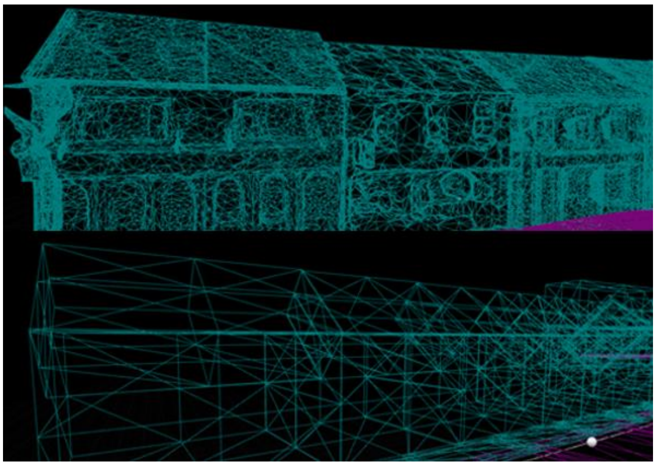

Figure 3- High-polygon vs Low-polygon mesh skeleton and the potential impact in immersion and perceived QoE

B. AV Simulator

The engine used to build both environments was the Unreal Engine 4.22.3 [29]. This platform allows us to create functions using C++ language and its own visual scripting system called Blueprint. Unreal is used for real-time manipulation of the content and known for delivering immersive experiences. It provides powerful physically based renderings, procedural meshes, custom lighting, shading, etc.

The simulation for both scenarios runs on the HTC Vive PRO Eye [34]. This HMD provides eye tracking capability and consequently the possibility to study attention and focus during the experience. The VR demonstration will bring the user on an AV experience as a passenger. During the experience, typical road events will be triggered. Whenever a response from the car is expected, the system is ready to collect user's metrics. It means for instance that if the traffic light becomes red, the HMD will track the user's eye gaze while the AV performs the correct maneuver (i.e. to stop the car in the right time). Considering that the events are the same for both scenarios, it will allow us to capture data to understand the influence of graphics rendering on user's QoE for virtual AV and potentially the correlation between photorealism, immersion and trust in technology.

IV. FUTURE WORK

Surveys used to identify the pathways towards the adoption of self-driving cars highlighted the concerns that the users still have. Objective and implicit psychological metrics need to be defined and understood as previous work has focused on the collection of subjective metrics in a variety of simulation setups. This demonstration endeavors to create a basis that fulfills the needs about assessing AV technology in VR. With objective and implicit metrics, we aim to understand what promotes the highest level of immersion (HMD) [27]. The possibility of rendering application's graphics in different levels allows the study of the impact of these quality features in the user's perceived QoE. In addition, the findings from this study will permit to understand the relationship between technology adoption, trust in AV, cybersickness and optimal feedback modalities for each of the promoted rendered graphics modality.

Figure 4- Preview of the high-polygon-based environment that will be used to compare user's QoE with the low-polygon type.

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