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A FLEXIBLE MULTI-MODAL MULTI-USER TRAFFIC SIMULATION FOR STUDYING COMPLEX ROAD DESIGN

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ABSTRACT

While there are many factors that affect traffic accidents, safe road design plays a key role. It is critical to understand traffic flow and driver response to various scenarios. Furthermore, with the inclusion of new traffic trends such as bicycle friendly roads and autonomous vehicles, it is ever more important to study the complex relationships between traffic entities. However, controlled experiments can be difficult to implement in the real world. Traffic simulation has been researched for decades to understand the flow of traffic in a variety of environments and how users interact within it. However, these platforms are limited in simulation and authoring capabilities, do not allow for multiple human agents, or are not accessible by roadway designers. This research explores the technical development of a multi-user multi-modal traffic simulation platform that expands on the capabilities of traditional traffic simulators. Traffic simulation of virtual cars and pedestrian agents were generated through VISSIM and networked into a simulation platform. Multiple human agents can interface with the system through a physical car and bicycle rig featuring both a virtual reality head mounted display and a multi-monitor display. Furthermore, the multi-user nature of the platform allows for a variety of complex research applications including multi-user behavior. By utilizing low-cost commodity hardware and software, the accessibility of this platform is greatly increased. A testbed environment was created to evaluate the technical limitations of the platform and assess where further work is needed. Through this evaluation, the authoring process and networking capabilities were optimized. Additionally, the core functionality of the platform, including the various simulator modes and multi-user functionality, was found to be successful. Through this research, combining commodity hardware with traffic simulation will allow a larger number of researchers to better understand traffic environments and how humans may interact within them.

1. INTRODUCTION

The Highway Traffic Safety Administration reported that in 2017 alone, 6.4 million traffic accidents occurred in the United States [1]. Determining what factors influence traffic accident rates, as well as decision making of a driver, has the potential to reduce the number of accidents by improving road safety standards. However, this can be difficult for road design researchers to investigate. The inability to find a controlled environment in which to conduct relevant experiments can prevent a study from producing valid data. This often makes traffic safety research tedious, inefficient, or outright ineffective. The random nature of road traffic means that studies in this area lack repeatability and are subject to confounding variables. Furthermore, in some cases it would be unethical to study a situation that may lead to putting someone in danger. A solution that has been developed over the past few decades is the utilization of computer simulations to create and analyze these driving scenarios [2], [3]. Through this technology, specific road designs, proposed construction projects, or existing road layouts can be tested in a controlled environment.

Some simulations allow user agents to interact within a virtual reality environment (VRE) to better understand human behavior in traffic scenarios. These simulations provide the benefit of placing a subject in a scenario that may remain constant over multiple sessions, making it much more feasible to control environmental conditions. Additionally, algorithms have been developed and optimized to accurately simulate the flow of traffic through city roads [4], [5]. The combination of accurate traffic simulation and an immersive VRE may make it possible to create complex traffic scenarios. However, when developing these systems, substantially more work must be put into creating an immersive VRE. Immersion, often described as the physiological state of perceiving yourself within an environment, is critical to the effectiveness of VREs [6]. The potential of putting someone into a truly immersive simulation, will open doors to new research. Methods that have been tested in the past include creating a realistic VRE, developing simulator platforms that facilitate life-like interaction with a simulation, and the utilization of VREs to enhance immersion. Several simulator platforms have been researched to facilitate driving a car, riding a bicycle, walking as a pedestrian, and several other modes of common city transportation [7], [8]. Furthermore, by incorporating multiple user agents using various types of transportation, numerous traffic scenarios may be studied.

The goal of this research was to develop a multi-user traffic simulator platform capable of generating life-like traffic that will interact with users on various simulator modes such as a car or bicycle. Furthermore, it was critical to ensure this system is as accessible as possible, i.e., may be accessed and used by a large variety of road design researchers. Therefore, the simulation platform was designed with low-cost commodity devices and software. VISSIM, a popular commercial traffic simulator was used for generating vehicle traffic, and comes with the ability to communicate data in and out of the program via network connection [7]. A car simulator was implemented to allow a user the ability to interact with the VRE from the perspective of a driver. In various traffic scenarios, cars are not the only vehicles involved. Therefore, a bicycle simulator was also developed using a bicycle on a stationary stand with low-cost Arduino boards and sensors [8]. While each of these aspects add considerable value on their own, by bringing them all together into a single VRE, it allows a road design researcher to better understand the big picture.

A variety of techniques were implemented to synchronize these simulators together within the same VRE. The Unity game engine was leveraged as the main development platform for its cross-platform functionality, tools to create VREs, and the ability to allow third party plug-ins [9]. Furthermore, networking capabilities were critical as a large amount of traffic data will flow through the various simulator clients. The Photon networking platform and a local Photon Server were implemented to control the network traffic and provide high level networking capabilities [10]. The computation traffic model provided from VISSIM was piped into Unity through a plug-in and populated the VRE with traffic. The car and bicycle simulators existed as separate clients and were networked within the same environment. Through this system, their pose was fed back into VISSIM to allow the computational model to adjust for the user agents.

This research provides insight on the technical development in developing a multi-user multi-modal traffic simulation platform. These efforts provide a means for traffic analysts to better understand traffic patterns, accidents, and behavior. By providing a combination of traffic simulation, driver simulation, and bicyclist simulation, it is possible to observe the various, complex interactions between these agents and gain a full understanding of how to improve the wellbeing and safety of those on the road. Furthermore, by targeting commodity devices, this simulation platform allows for better accessibility than traditional high-end expensive systems.

2. BACKGROUND

2.1 Traffic Simulation

The application of traffic simulation towards safe road design is critical to analyzing traffic patterns in various situations. The development of an effective traffic simulation model known as Gipps' Model, was arguably the first effective implementation of this goal [11]. Gipps presented equations containing different variables including reaction time, vehicle number, and acceleration constructed from past research. These equations could then present traffic data given different boundary conditions. After two decades of continued research, an open-source traffic simulation software, known as Simulation of Urban Mobility (SUMO), was developed to address the problem of easy access to traffic simulations [3]. SUMO was developed as a multi-modal, city-wide simulation software package. By using an extension of Gipps' model, the simulation could effectively work as both a microscopic simulation of individual cars and a macroscopic simulation of city-wide traffic [12].

As SUMO and additional traffic simulation packages have been embraced, software has been further developed in the community. Two of these developments include the implementation of three traffic scenarios set in Bologna, Italy, presented in 2015 and the development of a simulation package that includes three personalities of a driver [13], [14]. This was developed using An Integrated Wireless and Traffic Platform for Real-Time Road Traffic Management Solutions (iTETRIS) and data provided by the Municipality of Bologna. Bieker's team created several scenarios in the SUMO software, including a scenario for traffic around a soccer stadium. Ayres' team created a simulation package to include angry, neutral, and relaxed drivers that all follow different parameters when determining their driving decisions. Additionally, several commercial vehicle simulation packages have been developed. VISSIM is one such package that provides robust traffic modeling and is used heavily in industry.

2.2 Car and Bicycle Simulation

Notable progress has also been made in the development of realistic driving simulations. The advancement of these simulations has helped researchers investigate topics including increasing the safety of city and interstate driving and analyzing how drivers react to unexpected scenarios. A study by Liu et al., aimed to analyze one of these goals, improving safety, by discussing their designs for testing the ability of a driver to read road traffic signs in varying environments, along with their findings using this design [15]. This research suggested that VREs can be effective in understanding driver behavior leading to better road design.

Additionally, analysis into how to effectively create a convincing simulation environment has been a focus of many research efforts. Examples of this research include investigating how to easily create a photorealistic traffic environment and the analysis of creating easily reproducible traffic scenarios while keeping all non-experimental variables controlled in the scenario

[16], [17]. Both groups pursued the goal of creating a traffic environment that is controllable enough to perform experiments in, while still requiring relatively few resources to create.

Several groups have had the goal of improving the accessibility of Head Mounted Display (HMD) VR driving simulations. VR shows promise for use in various traffic simulators by increasing immersion within the VRE. However, the main drawback of VR for this application is the increase in simulator sickness among participants. Many researchers have pursued reducing the effects of simulator sickness that many first time VR users experience [18]. Fernandes et al., analyzed the effects of subtly varying the Field of View of a HMD simulation to reduce the effects of simulator sickness [19]. A similar study, by Jang et al., analyzed the effects of both driving and flying in VR [20]. This analysis used skin resistivity, heart rate, blood pressure, and several other variables as testing parameters for these various environments.

Parallel to the development of driving simulators, bicycling simulators have also been thoroughly studied. Research efforts showing that infrastructure built with cyclists in mind has had a profound effect on both cyclists per capita and the mortality rate of cyclists have encouraged the community to pursue these simulations [21], [22]. The efficacy of applying VR bicycling to real life infrastructure design has been investigated and supported, lending credence to the practice of analyzing the effect of infrastructure on cyclers' behavior through VR [23]. Additionally, several studies have shown various use cases for VR bicycling including increasing exercise performance for physical therapy purposes. [24], [25].

An initial problem that arises when building a bicycle simulator is designing an effective mechanical assembly for this simulation. Chen et al., presented a design which used a two Degree of Motion (DOF) motion platform, along with several derived kinematic equations, to effectively simulate motion of a bike in a computer [26]. Herpers et al. presented a similar design, which included a 6 DOF hydraulic platform which fed haptic feedback through its hydraulic system, into the user's bike [27]. These forces, calculated in the simulation, were able to simulate features like hills, bumps, and acceleration forces. The main issue with both simulators is that they require bulky and expensive hardware that would not be accessible for a variety of use cases.

The effects of bicycle simulation towards improving human health and safety have also been thoroughly analyzed. Ono et al., used an assembly that included an HTC Vive and a simple exercise bike to test whether college age students felt as though they were truly riding a bike [28]. By identifying shortfalls in their simulation, including simulator sickness and relatively short overall bike time per user, they were able to identify what needed to be improved to increase the validity of their safety focused design. While bicycle simulations have been the focus of many researchers, there has been very little research exploring multi-modal simulations that include other traffic entities like cars or pedestrians.

2.3 Multi-Modal and Multi-User Simulation

In additional to the different methods of traffic simulation, the idea of multi-modal VR experiences has also been analyzed. The benefits of developing multi-modally include a more convincing virtual experience, an increase in a simulation's ability to represent real scenarios, and an ability to utilize multiple types of vehicles in a simulation. Two of the most promising developments, seen in publications from 2012 and 2005 respectively, show the benefit from task training in VREs [29], [30]. These papers discuss the many potential uses of multi-modal simulations in training people for new tasks. These tasks include rowing practice, fine control of force application, and teaching intellectually disabled people how to safely navigate traffic and shop for groceries.

An example of one of these multi-modal simulations can be seen in the development of a simulation of Rennes, France [31]. In this paper, a system known as the Virtual Urban Environment Modelling System (VUEMS) was presented by the authors. Using VUEMS, cartographic databases, and traffic light organization charts, this group was able to create a 3D geometric representation of Rennes. Along with this model, this group included mechanical models for trucks and cars, as well as kinematic models of cyclists and pedestrians. By using VUEMS, this group has made it easier to create multi-modal simulations with similar-to-life geometric environments. More recently, a group presented a design for a multi-thread computed environment, and a distributed computed environment [32]. This simulation includes four different modes of simulated transportation: a public train, a public bus, a private car, and a pedestrian. By including several modes of transportation, this group was able to effectively analyze traffic patterns of 70,000 people in Dublin, Ireland.

Lastly, multi-user simulations allow for the study of multiple user agents within a single VRE. These simulations present an ability to collaborate with people while in a VR world. Examples of this collaboration in industry are seen in two papers: a discussion on the safety training for construction site cranes and an analysis of facility planning simulations with multiple users [33], [34]. In both publications, the application of multiuser simulations in industry were overviewed, and their benefits were discussed. The papers cited improved safety, improved ease of design for new facilities, and an improved user experience as some of the benefits of this technology.

These multi-user VREs have the potential to be improve the effectiveness of traffic simulation. The benefits of multi-user traffic simulation include interacting with other people in these traffic scenarios and adding a layer of unpredictability when running these scenarios. In a single-user VR world, the user is interacting with only manufactured traffic behavior, but with multiple users, this traffic has the unpredictability of true human drivers. To increase the effectiveness of multi-user VR traffic simulations, research has been conducted to effectively implement and utilize networked multi-user driver simulations. An analysis of the state-of-the-art, compiled three world class networked driving simulators, and compared how each system is implemented. By comparing these systems, this group was able to discern the tradeoffs of each system, including networking limitations, a lack of standardization, and low simulation [35].

The result of these research efforts has been a rapid development in the field of traffic simulation. Faster, more accurate mathematical traffic models, more effective multi-user networking, more convincing car and bicycle simulation, and an increased streamlining of environmental design have all seen progress as an effect of this research. Now, an effort must be made to combine all these aspects into one multi-modal, multiuser, traffic scenario simulator. Through the development of these simulators, civil engineers may better understand the intricate interactions that take place during various traffic scenarios.

3. METHODOLOGY

The methodology section will describe the hardware, software, and various techniques to create the multi-user multi-modal simulation platform. The goal of this research is to develop this simulation platform in order to study how drivers, bicyclists, and pedestrians interact in various traffic scenarios. The following sections will discuss the hardware and software choices made to maximize accessibility by utilizing low-cost commodity devices and development tools.

FIGURE 2: CAR RIG AND MULTI-MONITOR DISPLAY

3.1 Hardware Implementation

Due to the multi-modal nature of this research, numerous hardware devices were implemented within this traffic simulation platform. To achieve realistic visuals, two separate approaches were implemented, a VR HMD and multi-monitor display, shown in Figures 1 and 2. Both approaches feature various trade-offs that must be considered depending on what is being studied in the scenario. The VR mode was implemented using the HTC Vive system. The HTC Vive system, a popular and established commodity VR HMD, features comparable specifications to other commodity HMDs. The HTV Vive features a 2160x1200 resolution display with a field of view of 110 degrees. While this VR HMD lends itself to an impressive immersive VR experience, it is known to cause simulator sickness in visuals that induce high optic flow [36]. The mismatch between the vestibular system and visual display tends to add to the effects of simulator sickness [37]. To help mitigate this, a vignetting technique, like adding a rest frame, was implemented. A rest frame essentially involves rendering a static object within the virtual scene to reduce optic flow and give the user something stable to focus on. The idea of this technique is to reduce optic flow in situations where there is an abnormally high amounts of optic flow, such as turning or moving quickly [38]. This helps reduce the amount of simulator sickness a user may experience and help increase the amount of time a user may be able to interact with the simulator.

Figure 1: BICYCLE RIG AND VR HMD

Despite techniques to mitigate simulator sickness, no solution is perfect. In some situations, it may be advantageous to sacrifice immersion for comfort. For these scenarios, a multi-monitor display can be utilized to provide front and side views for the driver to have an almost complete view of what the driver would see in real life. While there is still a mismatch between the vestibular system and optic flow, the optic flow is limited to the monitors and is greatly reduced. Furthermore, if the user doesn't have access to a VR HMD, this simulator is still viable using a multi-monitor display, leading to increased accessibility.

In addition to visuals, the simulator needed to provide a realistic input methodology. Therefore, a Logitech G25 steering wheel and pedals were included so a user was able to drive the vehicle the same way they would in the real world, shown in Figure 1. A Logitech software plug-in allowed the device to communicate with Unity's physics engine. While the implementation of the steering wheel and pedals provide a more realistic experience, they do lack various haptic cues such as the feel and weight of the car. While it is possible to recreate these cues with expensive haptic devices and sensors, this method sacrificed a small amount of realism for a more accessible system.

Like the driving simulator, the bicycle simulator had to provide realistic visuals to a user. The same methodology for the driving simulator was implemented for the bicycle. This features a VR and multi-display mode available depending on the scenarios and research goals, shown in Figure 2. The issue of simulator sickness was observed to be substantially prominent with bicycle simulator than with the car simulator. This is likely due to the lack of rest frame when riding the bicycle. In the driving simulator, it is possible to see the interior of the car which reduces optic flow and gives the viewer's eyes something to focus on in moments of high optic flow. When using the bicycle, there is no rest frame and therefore, the user is more susceptible to simulator sickness.

Figure 3: VISSIM TRAFFIC VISIBLE IN UNITY CLIENT

The bicycle simulator needed to reconstruct the feel of riding a bicycle and therefore a bicycle mounted on a stationary stand was used. This bicycle was rigged with a reed switch and magnets to detect the rotation of the tire. Since the switch needs at least two measurements to calculate an initial speed, there would be a lag between when the user pedals the bike to when the virtual bicycle starts moving. Therefore, numerous small magnets lined around the tire was used to minimize this lag and make the input system more responsive. A simple bike turning mechanism was implemented by allowing the handlebar to swerve left and right while keeping the front wheel stationary. While this is in contrast to the natural tendency of bike riders to lean left/right while making turns, this approach reduced the cost of having an expensive mechanism in place. A potentiometer was placed on the handlebar to capture and measure turns. To make this feel more natural, a small gain was added to the rotation, so the user did not have to drastically rotate the handlebars to turn.

3.2 Development Tools

In addition to synchronizing a variety of hardware devices, a major focus of this research was to leverage numerous software and development tools to create this traffic simulator platform. Since the main objective of this research was to create a multi-user multi-modal experience, it was critical to target a development platform that provided multiplatform build support. Unity became an obviously choice due to a variety of tools to build VREs and its multiplatform build support. The driving and bicycle simulator were developed using Unity which provided support for the aforementioned hardware devices.

Traffic generation was accomplished using the traffic simulator program VISSIM. The software is commercially available and has an extensive support structure such as cross-platform Document Object Model (DOM) connectivity allowing network interactions with Unity. Additionally, the program provided simplified Unity connection script examples that helped vastly reduce the burden of code development. Furthermore, it allows for the networking of data in and out of the simulation. This allowed for the implementation of a Unity plug-in to visualize the traffic flow within a Unity client, shown in Figure 3.

Finally, it was paramount to bring these various simulators together into a unified network connected environment. To achieve this, it was critical to have a networking system that could handle a large amount of traffic related data. The main two networking platforms include Unity's built in Unity Network (UNET) and Photon Unity Networking (PUN). While UNET is native to Unity, there is a lack of support and limitations when it comes to bandwidth. Due to the limitations of the UNET tools, a third-party plugin PUN was implemented. Among other features, PUN provides the capability of hosting and managing an on-premise server that can seamlessly handle network traffic for thousands of vehicles simultaneously.

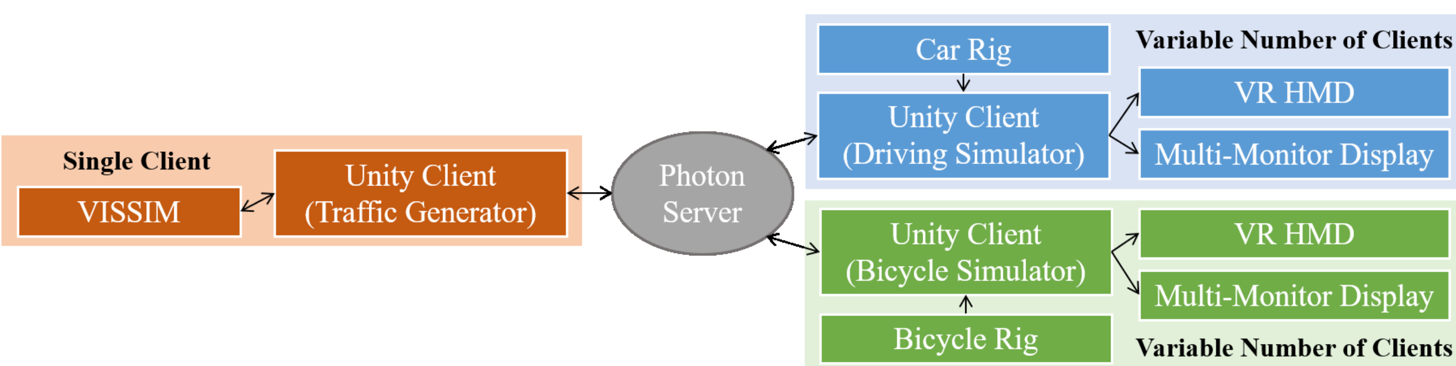

Figure 4: NETWORK ARCHITECTURE

Figure 5: AUTHORING PROCESS

3.3 Network Architecture

Due to the large amount of network traffic that would be necessary for many scenarios, a network architecture had to be designed to accommodate this. The approach taken was to create a central Photon Server that would route the necessary data to each client as shown in Figure 4. In the architecture developed, the clients are the physical bicycle and car driving simulators and are peer-to-peer network connected. Their states are synchronized with VISSIM traffic via the Photon server implemented in Unity. The clients are recognized within VISSIM as traffic entities just like other vehicles generated by the traffic simulator. For example, if VISSIM generated 1,000 vehicles in its program, the introduction of a bicycle and two car simulators from the Photon server will make VISSIM compute traffic behavior for 1,003 vehicles. This behavior is broadcasted to the bicycle and car simulator clients in real-time using VISSIM's DOM and the PUN server. The make of the architecture allows for the system to function without a crash even if one or more clients get disconnected, making it highly scalable.

3.4 Scenario Authoring

The framework developed combines both hardware and software technologies from disparate sources. Sustained usage of the framework will be dependent on being able to author scenarios that addresses the changing needs of researchers, engineers, and traffic incident managers. In order to realize the full potential for the developed system, a scenario authoring system was needed. Ideally, this will involve an interactive means of creating a computational road network readable by VISSIM and its associated 3D mesh geometry used for rendering purposes by the Unity engine. These goals however, turned to be competing objectives and side projects by themselves eventually requiring the team to make tradeoff decisions. For example, a computational road intersection authored in VISSIM for generating traffic can be imported within Unity for visualization purposes. However, VISSIM is not designed to cater for the aesthetics of the mesh generated. This results in artifacts such as visually unappealing mesh geometry such as gray colored sidewalks, dark gray bumpy road corners, and traffic signals appearing as red/amber/green roadblocks. Cultural features such as houses, office buildings, and parks do not come as a standard offering by VISSIM. On the other hand, it is possible to create a traffic intersection geometry on 3rd party programs such as Sketchup, Blender, 3DS Max, with all desired cultural features and easily import within Unity. VISSIM, with its limited 3D mesh import capabilities (i.e., Sketchup file format), can load in the mesh geometry and allow a user to author and overlay computational road for traffic generation. Once created and executed within VISSIM, the network architecture detects traffic state changes and are relayed to bicycle and car simulator clients. Traffic light signal events relayed by VISSIM are mapped to appropriate red/amber/green traffic light mesh geometry within Unity. Both of the above approaches turned out to be viable alternatives for scenario authoring in the framework developed as shown in Figure 5.

Regardless of the approach used, manually building a traffic scenario within VISSIM, at least in its current form, was an unavoidable requirement without a possibility for auto generation. All traffic simulators investigated as a part of literature search prior to this project commencement required some form of authoring for generating vehicle traffic. This research builds on the literature to provide a straightforward efficient methodology for the authoring process.

4. Evaluation and Testbed Scenario

Through this multi-modal multi-user simulation platform, a traffic environment was created to test the functionality of the system in a town and highway road system, shown in Figure 6. The core aspects of the platform were evaluated including the authoring process, multi-modal functionality, and multi-user functionality.

This VRE was generated from the authoring process described in the methodology section. Details such as road lines are tedious but have a significant impact in aesthetics and understanding of the VRE. By creating templates of textures, this process was greatly sped up and allowed for quick and efficient authoring. The authoring methodology developed in this paper allowed for an efficient creation of the traffic VRE.

Once the authoring was complete, the traffic generator, driving simulation, and bicycle simulation were all tested within the VRE to evaluate the multi-modal aspect of the platform. Each individual system functioned as expected, traffic was correctly generated within the environment, visuals were displayed correctly, and input from the car and bicycle rig was successful. Each mode performed at a sufficiently high framerate, over 60 frames per second, with little to no input lag from the various hardware devices.

Figure 7: FULL OVERVIEW OF TESTBED ENVIRONMENT

Finally, the various modes were tested within the same VRE to evaluate the multi-user aspect and networking capabilities of this simulation platform. Each of the modes performed as expected while in the environment together. Figure 7 shows multiple clients within the same VRE, user agents are marked with a sphere over their respective vehicle. Each user agent was able to identify the other user agents and generated traffic within the VRE. The main issue that arose was the heavy network traffic generated by the numerous cars and pedestrians in the environment. This was mitigated by interpolating the pose of the various vehicles and pedestrians between network packets. It was possible to reduce the number of packets sent and still maintain smooth visuals. Overall, this testbed VRE demonstrated the capabilities of this simulation platform and allowed for the further optimization of the various simulators that are included. A more detailed evaluation will be performed in the future, this initial evaluation was intended to demonstrate any flaws in the system design.

5. CONCLUSION

Helping road design researchers better understand various traffic scenarios is critical to creating safe and efficient roadways. Studying traffic patterns in the real world can be tedious, inefficient, and ineffective. By utilizing VREs to study a variety of traffic scenarios, valuable data can be collected to better understand the complex interactions between drivers, bicyclists, and pedestrians.

This research provided an approach to creating a multi-modal multi-user traffic simulator. The various modes of this simulator platforms allow for the simulation of traffic, bicyclists, and drivers. Furthermore, Network synchronization of these modes allowed for studying complex interactions between entities on a roadway. To achieve this goal, various hardware and software packages were implemented and customized to seamlessly interact with each other. A testbed scenario was developed to evaluate the technical aspects of the simulator platform. This scenario helped identify inefficiencies with the authoring process as well as limitations with the simulator platform itself. Through this process, the workflow was optimized to create a smooth multi-modal multi-user experience that could be used to study a vary of traffic scenarios. Finally, by utilizing low-cost hardware and software, the accessibility of this platform is greatly enhanced. Traffic analysts would be able to examine various traffic scenarios much easier than what was possible in the past.

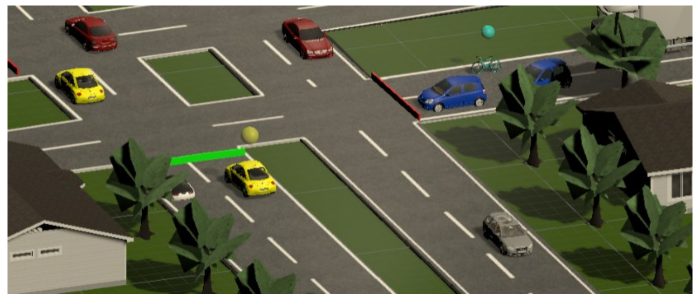

Figure 6: MULTIPLE USERS IN VIRTUAL ENVIRONMENT

6. FUTURE WORK

While this research provides the technical description of bringing various hardware and software packages together, understanding how the user will use such a system is critical to providing a quality user experiences. As such, the first suggested future direction for this work would be to conduct a formal user study to better understand the usability of the system and how it could be improved. The second suggested future direction is to gather observations from the user study and list out possible directions to mitigate simulator motion sickness, especially when wearing an HMD. A third suggested future direction is to measure the physiological responses of bike and car riders using biosensors to study their stress, cognitive and aggression levels.

Enhancing the multi-modal aspect of this platform would also add immense value. Currently, a driving and bicycle simulator was implemented. However, there are many other entities that you would find in a traffic scenario such as pedestrians, workers, and even autonomous vehicles. By allowing for these additional modes, it would be possible to create more complex traffic scenarios. This would allow civil engineering to further understand the intricacies of traffic flow and provide safer and more efficient roadways.

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