Real-Time Control of Physical Vehicles via Internet-Enabled Simulators

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Abstract: - This thesis explores the concept of controlling real cars using simulators connected through the Internet. The convergence of advanced technologies, such as virtual reality, the Internet of Things, and artificial intelligence, has paved the way for innovative approaches to remotely control physical objects. This study investigates the feasibility and potential benefits of employing Internet-connected simulators to control real-world vehicles, highlighting the implications for transportation, safety, and user experience. Through a combination of theoretical analysis, software development, and practical experimentation, this research aims to contribute to the emerging field of remote vehicle control and expand the possibilities of mobility in the digital age. By investigating the potential of using Internet-connected simulators for controlling real vehicles, this thesis aims to contribute to the advancement of remote-control technologies and their impact on transportation. It explores the technical aspects, user experience, safety considerations, and ethical and legal implications involved in implementing such a system. The findings and recommendations presented in this thesis can serve as a foundation for future research and development in the field of remote vehicle control, ultimately shaping the future of mobility in the digital era.

Key Words: - *Simulator, Virtual Reality, Artificial Intelligence, Remote-Control Technologies.*

I. Introduction

1.1. General

The concept of simulation can be defined as the emulation of a specific behavior through a generic imitating system. Simulate is the word that have same meaning as fabricate, feign, pretend, copy, mimic, or imitate. The word “simulation” can be defined as a "technique of substituting a real environment to fake one, so that it is possible to work under laboratory conditions of control. Within experimentally controlled environment, performance measures can be defined, collected, and repeal tested which is in a cost-effective manner (Olsen 1996).

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A virtual driving simulator is a device that allows user to feel a life-like experience of driving an actual vehicle within virtual reality.

The virtual driving simulator environment consists of static universe, dynamic objects and interior of driver’s vehicle (Kang et al. 2004). The static universe can be building, trees, road and others. The dynamics objects can include any moving objects in virtual scene like cars, people, and crowd. With more complex virtual scene will contain many thousands of polygons which need more graphic processing power and more computation cost to render the scene. Even on latest graphic hardware processing, the increase in complexity in virtual environment will increase computational power.

1.2. Concepts of The Interactive Simulators

The very first simulation systems can be found at a beginning of air force pilots training procedure. Training in real planes meant higher training cost and high danger rate for novice pilots. After such successful launch of pilot training simulators, other vehicles simulators came quickly. The most widespread have become the car driving simulators. The simulator systems used to be developed for use in three separated fields:

- Training
- Research
- Entertainment

Originally, different ways of use of the simulators in the above noted fields have merged during decades of their use and development.

1.3. Human Perceptual System

In driving simulators, multiple systems are combined to form the self-motion perception as further detailed. Because driving is primarily a visual task, one of the most important human sensors to be accounted for in driving simulation is the visual system. In fact, the visual system accounts for the majority of motion perception in a three-dimensional environment. The optical flow together with visual direction and extra-retinal direction form the visual information to be interpreted by the brain in order to define heading. Although less important than the visual system, the auditory system can also be classified as a self-motion perceptual system. It is proven that through audio means only, separate from other sensory systems, individuals are able to identify, with certain precision, the time-to-collision of sources of noise. Interesting research is conducted where the authors concluded that adding auditory cues to visual cues increases the illusion of motion.

1.4. Types of Simulators

Simulators can be divided as interactive and non-interactive. Interactive driving simulator mean that the simulator responds to the driver just as the driver responds to the simulator or called as a closed-loop driving simulator. Apart in a non-interactive system, the driver responds to the simulator, but the simulator does only what it was programmed to do, regardless of the driver's actions, often referred to as an open-looped system. Interactive driving simulation represents real world such as actual roadways through computer generated imagery (CGI), auditory feedback, and realistic vehicle instruments and controls such as brake pedal, steering wheel, turn signal indicator, speedometer, and mirrors. CarSim and Truck Sim are being used in a wide variety of driving simulators. If we want a low-cost turnkey driving simulator from Mechanical Simulation, we can get CarSim DS or TruckSim DS.

II. Literature Review

Rashmi Singh, [2]Shristi Priya, [3]Ria Nair, [2]C. Ashwini: Smart Transportation System with Simulator Testing- Internet of Things, a colossal network of everything around you and your internet, the trend of today, inspires a striking change in the transportation system. This paper focuses on a self- aware vehicle with internal data analytics, a data management system to anonymously collect and examine data for better routing plans and early warnings and a simulator to avoid the risk of testing such a vehicle system on road.

Xincheng Cao, Haochong Chen, Sukru Yaren Gelbal, Bilin Aksun - Guvenc* and Levent Guven: Vehicle in Virtual Environment Method for Autonomous Driving System Development, Evaluation& Demonstration this paper introduces the Vehicle-in-Virtual-Environment (VVE) method of safe, efficient and low-cost connected and autonomous driving function development, evaluation and demonstration. The VVE method is compared to the existing state-of-the-art. Its basic implementation for a path-following task is used to explain the method where the actual autonomous vehicle operates in a large empty area with its sensor feeds being replaced by realistic sensor feeds corresponding to its location and pose in the virtual environment. It is possible to easily change the development virtual environment and inject rare and difficult events which can be tested very safely.

Y. Azuma[1], T. Kawano[1] T. Moriwaki[2]: Evaluation Methods for Driving Performance Using a Driving Simulator under the Condition of Drunk Driving or Talking Driving with a Cell Phone- The purpose of this study is to fabricate a driving simulator and establish the methods to evaluate the driving performance using the simulator under the condition of drunk driving or talking driving with a cell phone. Two indices are proposed to evaluate the driving performance. One is the degree of unsteadiness of the driving path and the other is the reaction time in pressing the brake pedal with a foot.

Kuang Hua Chang: Motion Analysis- Many products or mechanical systems involve moving parts. Parts must move in a certain way to perform required functionality and achieve desired performance. Components must not collide or interfere with each other during normal operations. The system must be efficient (usually lightweight) yet durable.

III. Mathematical Model

3.1 Design of DS

As it was possible to see from the previous chapter, the simulators have different construction topologies. The topology is often connected with the simulation fidelity but they are tightly coupled with the system cost. Although the simulators producing the majority of available cues in the largest ranges are considered as high-fidelity simulators, they do not necessarily fit best to all experiment types. Even the most expensive systems still only approximate the real driving experience. As a result, there is only a model more or less satisfying need so each particular experiment.

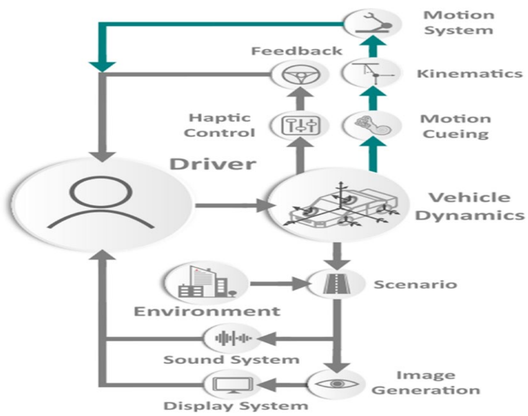

Fig.1. Diagram of a driving simulator

3.2 Vehicle Dynamics Model

The model is defined as a simplified system that reproduces the characteristics of a more complex software is dedicated to the vehicle dynamics model. This model must contain a mathematical representation of the vehicle subsystems (i.e., body frame, suspension, tires, brakes, steering and power train) and it must be able to compute the dynamic behavior relative to a fixed global orientation system, calculating component forces and non-line arties.

3.3 Scenario Design

Another key feature of driving simulator is the possibility of creating specific scenarios. In driving simulation, a scenario can be described as an event that happens in a virtual environment. The event can be a predefined situation, e.g., a pedestrian crossing in front of the ego vehicle, or a situation created by the driver, e.g. a sign with dwell maneuver.

3.4 Visual Cues

These digital graphics rapidly improved from a low number of polygons to high count textured and shaded polygons that provide a highly realistic environment for use in driving simulation. In addition, the improvement of projector technology with increasingly higher pixel resolution, brightness, and contrast ratio, made the accurate projection of such graphics possible.

3.5 Auditory Cues

The importance of the audio cues is justified by how it affects speed judgment, driver awareness, and fatigue... In this work, an experiment is conducted with subjects of different age ranges (young and older adults) that are exposed to driving tasks where visual cues to self-motion are provided while the respective presence/absence of auditory cues is manipulated.

3.6 Motion Cueing Algorithm

The presence of a motion system requires the inclusion of a motion cueing algorithm. This algorithm is responsible for creating the displacements of the motion system accounting for human perception and the available workspace; therefore, its role is to govern the motion of the simulator to provide the driver realistic driving sensations.

3.7 Kinematics

The kinematics algorithm plays an important role connecting the motion cueing commands with the motion systems structure and hardware. The output of the motion cueing algorithm is trajectory of the cabin in Cartesian space, and this trajectory must be achieved by varying the length of the actuators.

3.8 Motion System

The better the motion system is matched with the vehicle dynamics model, likely the higher the fidelity of the motion will be. There are several mechanisms to reproduce vehicle motion, from low fidelity systems with 2-DOF and 3-DOF, to high fidelity systems with up to 13-DOF.These mechanisms can be comprised of serial and/or parallel actuators.

3.9 Mathematical–Physics Simulation Engine

The model of the car is created with the use of linear integral-differential solver. Online processing of input data (signals from the devices representing driver's controlling actions) is a basic Gear shifter position requirement on mathematical model of physical behavior of any interactive simulation system.

3.10 Visualization System

Most of the information that the driver's brain needs for driving (i.e., Correct response to the outer condition sand various stimuli) are visual ones. From the observed virtual scenery, the driver gathers information primarily about:

- Shape and color of the surrounding objects (including the road)
- Distance of the objects
- Self-movement (eventually the relative movement of other objects)
- From those primary cues, he/she derives secondary information about:
- Self(car)velocity in all directions
- Limited range of self(car)accelerations in all directions

- Weather conditions
- Road condition
- Surrounding objects (obstacles) and their movement
- Surrounding traffic
- Contextual information (sign posts, pictograms, texts, traffic lights, etc.)

3.11 Audio System

Besides the visual information, the second most important one is the sound information. It accomplishes or substitutes the visual and other cues coming in to the driver's senses. From the virtual sound, the driver can get information about:

- Car velocity
- Engine velocity and load
- Interaction with different types of road surfaces
- Sound properties of surrounding environment (open road, tunnel, corridor, bridge, forest, etc.)
- Surrounding traffic
- Collisions

3.12 Steering Wheel

The system that is necessary to be emphasized is the feedback on the steering wheel. This is actually the most direct way of how the driver feels reactions of the car to his/ her control actions. The correct behavior of a feedback of the steering wheel is essential for correct path keeping.

3.13 Hap tics, Motion Cueing

Both of the frequently used simulators - the steady based or motion based-can be equipped with additional feedback devices. They should provide more realistic feelings from driving. The aim of their use is to stimulate mechanical feedback coming either from the car itself or from the environment (e.g., road, blasts of wind). Motion platforms used in modern simulators are quite complex, mainly from the point of intelligent control, which should give the driver mechanical (based on forces acting on his/her body) responses from driving, utilizing only limited range of accelerations.

3.14 Driving Performance Assessment Tools

The aim of the tests is the objective assessment of user interface quality, human-machine interaction reliability (correctness, information understanding), positive virtue of the provided assistance and severity of possible negative impact (secondary load). Measurement (recorded data) on the vehicle simulators can be divided into two elementary groups, the objective measurement and the subjective measurement.

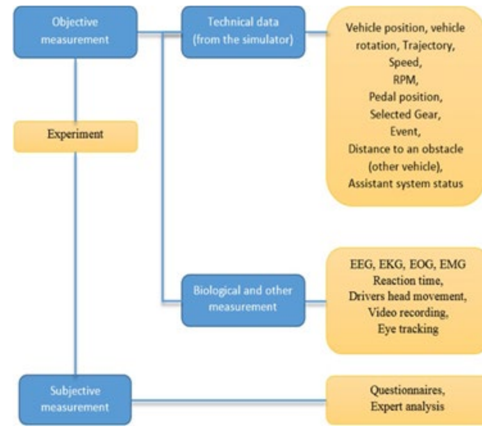

Fig.2. Diagram of measured data

3.15 Structure of The Vehicle Simulator

The main concept of the vehicle simulator is shown in Figure 2. The driver sits in the driver seat and controls the accelerator and brake pedals, the steering wheels and the transmission selector lever such as in real life, but the vehicle does not move. The simulation of the vehicle model and the environment (road, terrain, etc.) are run on the simulator PC. The simulation software calculates the vehicle motions by validated vehicle models then the scene is visualized in real time. The visualization of the vehicle and the environment are projected in front of the driver by a projector.

3.16 Driver Simulator

The driver simulator simulates the driving scenarios which are used to capture driving behavior under different conditions. It resembles the interior of a vehicle to give an accurate driving feel to the participants.

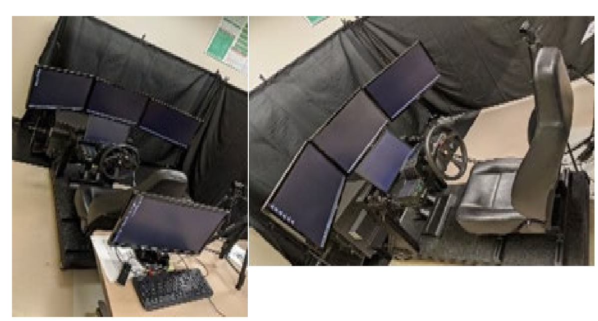

Fig.3. Driver Simulator

3.17 Vehicle Control Panel

During the development of the vehicle control panel, it was a basic requirement to reach the essential sensor information of the electronic system of the vehicle. The specific signals are sent to the simulation PC via the vehicle control panel. The control panel contains standard J1939 duplex CAN gateway electronics, and it is extended with other components which ensure the comfort and safe operation of the simulator system such as an engine sound generator and operation mode selector electronics.

3.18 Operating Modes of The Vehicle Control Panel

The vehicle control panel installed on the Audi TT Coupe has the following operating modes.

3.18.1 Normal mode

In normal mode the vehicle operates normally‟, i.e., like a conventional road vehicle. This mode is safe: the additional electronic devices installed subsequently are isolated galvanic ally from the original electronic system of the vehicle. This mode is used for regular travelling. If the emergency switch placed in the middle of the vehicle console is pushed, the system returns into this mode.

3.18.2 Sensor test mode

In the sensor test mode, a simple and quick test of the control panel and the communication system can be run without any other devices (e.g., a PC). In this mode, the accelerator and brake pedal position, the steering wheel angle and the selected gear are displayed on the vehicle dashboard.

3.18.3 Demonstration mode

In demonstration mode, the embedded software of the control panel runs a demo which demonstrates the main outputs (e.g., dashboard functions and sound generator) of the gateway without any additional devices.

3.18.4 Autonomous simulation mode

In this mode, the control panel simulates a simplified vehicle model in order to test the main function sand the communication of the simulation system without any additional devices such as a simulation PC. The accelerator and brake pedals, the steering wheel, the transmission selector lever and the simulation function of the dashboard can be checked easily in this operating mode; the sound generator provides the engine sound, as well.

3.18.5 PC simulation mode

The PC simulation mode is the most relevant operating mode in the vehicle simulator system. In this mode the vehicle is used as an HMI of the simulation run on the simulation PC. Furthermore, it provides feedback of some information to the driver by displaying the vehicle speed, engine rpm, etc. on the dashboard. The simulation mode is safe: the vehicle engine cannot be started in this mode.

3.18.6 Measurement mode

In the measurement mode the vehicle operates in the same way as in normal mode but the vehicle control panel still has the contact with the electronic system of the vehicle. In this mode, the vehicle control panel functions as a gateway; it reads the CAN messages on the five separate CAN buses of the vehicle and the additional sensor modules, then transmits the relevant messages to the PCCAN interface card. For safe operation, it is for bidden to send any messages towards the vehicle. The structure of the measurement system is shown in Fig. 5

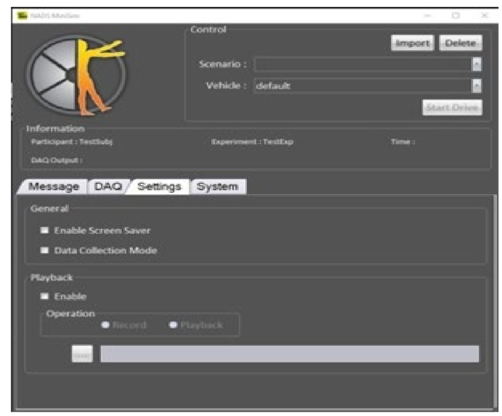

Fig.5. The structure of the measurement system

3.19 Simulation Software

The vehicle model, the road, the environment and the scenario of the simulation are built in CarSim. CarSim is stand-alone simulation software which contains a number of validated complex vehicle models of passenger cars, racecars, light trucks and utility vehicles. Custom vehicle component model scan be built as well or even replaced by external custom models; e.g., models built in Simu link or even written in C programming language. The software is able to use its own solver and cooperate with external software such as MATLAB

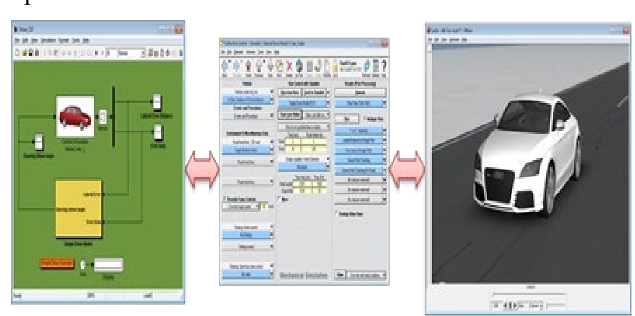

Fig.6. Screenshots of the simulation software

3.20 Data Verification Extraction

The ISAT allows for the verification of created scenarios and the extraction of data from the simulation. The ISAT provides four different modes that target different levels of scenario development. The authoring mode enables users to add new elements to the scenario or edit the existing elements. The rehearsal mode generates a walkthrough of the conditions in a scenario. The rehearsal mode runs the scenario on the ISAT platform using an autonomous driver model and any element can be followed. Since the driver is an autonomous model (similar to an ADO), it is more precise than a human participant in the simulation.

3.21 MiniSim^{TM}

Along with participant simulations, miniSim^{TM} offers several options that can be handy for users. Every simulation automatically generates DAQ files with time and date stamps. In addition to this, a text file is generated that can capture eleven different variables. The authoring needs to be done in the ISAT to prompt the capture of the variables. However, only up to twenty events can be captured by this method. The driving report can be viewed immediately on the screen at the end of a simulation by selecting the option in miniSim^{TM}.

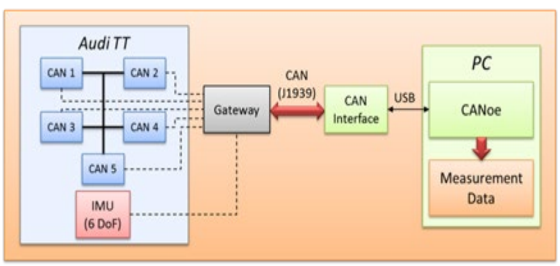

Fig.7. Initialization Window in miniSim^{TM}

3.22 Scenario Building

This section presents the types of scenarios that were developed or analysis. Three types of setups were developed (urban, rural, and freeway) in the driver simulator, based on common real-world conditions. This ensures results can be attributed to general driving behavior rather than limiting their applicability to only one type of setup. Since this study aims to test the effect of different types of advanced features on driver behavior, various conditions were also simulated.

3.23 Ultrasonic Sensors

These sensors use ultrasonic waves and operate in the range of 20–40 kHz. These waves are generated by a magneto-resistive membrane used to measure the distance to the object. The distance is measured by calculating the time-of-flight (ToF) of the emitted wave to the echoed signal. Ultrasonic sensors have very limited range which is generally less than 3 m. The sensor output is updated after every 20 ms, making it not compliant with the strict Quos constraints of an ITS.

3.24 Radar: Radio Detection and Ranging

RADARs, in AVs, are used to scan the surroundings to detect the presence and location of cars and objects. RADARs operate in the millimeter-wave (mm-Wave) spectrum and are typically used in military and civil applications such as airports or meteorological systems. In modern vehicles, different frequency bands such as 24, 60, 77 and 79 GHz are employed and they can measure a range from 5 to 200 m. The distance between the AV and the object is calculated by measuring the ToF between the emitted signal and the received echo. In AVs, the RADARs use an array of micro-antennas that generate a set of lobes to improve the range resolution as well as the detection of multiple targets.

3.25 Lidar: Light Detection and Ranging

LiDAR utilizes the 905 and 1550 nm spectra. The 905 nm spectrum may cause retinal damage to the human eye, and, therefore, the modern LiDAR is operated in the 1550 nm spectrum to minimize the retinal damage. The maximum working distance of LiDAR is up to 200 m. LiDAR can be categorized into 2D, 3D and solid-state LiDAR [19]. 2D LiDAR uses the single laser beam diffused over the mirror that rotates at high speed. 3D LiDAR can obtain the 3D image of the surrounding by locating multiple lasers on the pod. At present, the 3D LiDAR can produce reliable results with an accuracy of few centimeters by integrating 4–128 lasers with a horizontal movement of 360 degrees and the vertical movement of 20–45 degrees.

3.26 Cameras

The camera in AVs can be classified as either visible-light based or infrared-based depending upon the wavelength of the device. The camera uses image sensors built with two technologies that are charge-coupled device (CCD) and a complementary metal-oxide-semiconductor (CMOS) [18]. The maximum range of the camera is around 250 m depending on the quality of the lens [13]. The visible cameras use the same wavelength as the human eye i.e., 400–780 nm, and is divided into three bands: Red, Green and Blue (RGB). To obtain the stereoscopic vision, two VIS cameras are combined with known focal length to generate the new channel with the depth (D) information. Such a feature allows the camera (RGBD) to obtain a 3D image of the scene around the vehicle.

3.27 Sensor Fusion

Real-time and accurate knowledge of vehicle position, state and other vehicle parameters such as weight, stability, velocity, etc. are important for vehicle handling and safety and, thus, need to be acquired by the AVs using various sensors. The process of sensor fusion is used to obtain coherent information by combining the data obtained from different sensors.

3.28 Vehicular Ad-hoc Networks (VANETS)

VANETs are an emerging sub-class of mobile ad-hoc networks capable of spontaneous creation of a network of mobile devices/vehicles. VANETs can be used for vehicle-to-vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication. The main purpose of such technology is to generate security on the roads; for example, during hazardous conditions such as accidents and traffic jam the vehicles can communicate with each other and the network to share vital information.

3.29 System Overview

This article focuses on the building of an extensible platform that can acquire physiological and performance measures and it is planned to be used to acquire data in two scenarios: with drivers in sleep deprivation and under the influence of alcohol (DUI). It is important to acquire data of the second scenario because it has been shown that the effects of drowsy driving are very similar to driving under the influence of alcohol. The system was developed in three modules: Simulator, ECG processing, and Data distribution. One core novelty of this simulator is the inclusion of an ECG sensor embedded into the steering wheel, integrating a custom version of Cardio Wheel being developed by Cardio ID Technologies that was adapted to the driver simulator steering wheel.

3.30 Driving Simulator

All the experiment data were obtained through a driving simulator The driving simulator consists of four main parts: vehicle dynamics model, game-type driving peripherals, virtual driving environment, and human driver. The inputs applied by a human driver, including the steering angle, throttle opening, and braking force, were recorded through the game-type driving peripherals. The vehicle-dependent data such as vehicle speed and vehicle position were recorded from MATLAB.

3.31 Driving Environment

In this work, we fixed our attention on the longitudinal behavior when following a curvy road. The road factors have a big influence on the performance of driving style recognition. The road model must have the same scale as the road in the real driving environment. Therefore, the requirements of road model were subject to the following criteria: continuity of the path, continuity of the curvature, and differentiability of the set path. Drivers were instructed to drive in their lane and follow the reference path designed using Carsim data, as shown in the top figure of Fig. 6.

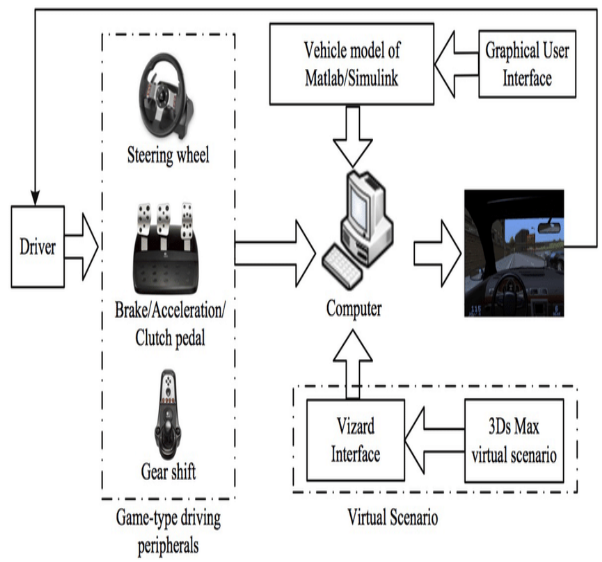

Fig.8. Experiment and data collection

3.32 Driving Environment

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3.33 Vehicle Simulation System (VSS) Control

In the case of the VSS vehicle, there is an additional specific goal, the control of the platform end-effector acceleration in two directions and two angular accelerations about those two directions. The complexity of a vehicle control is reflected in the fact that a cable cannot push a body, and this fact requires establishment of significant restrictions on the controller outputs. Moreover, complexity added by non-linear kinematics and dynamics equations.

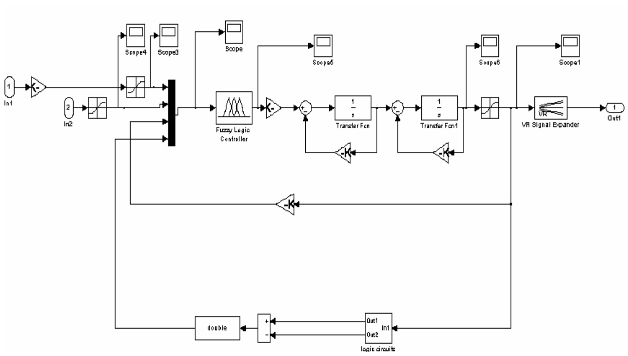

Fig.9. Fuzzy logic control of the roll angle

3.34 Data Collection Procedure

All the driving data were collected at a sampling frequency at 50 Hz in the driving simulator, including vehicle speed (v), throttle opening (α), acceleration, vehicle position, steering angle, and yaw angle. Eight driver participants were selected in our experiment, four of them were aggressive drivers and the other four were normal drivers. Each participant should be labelled as aggressive or normal before running an experiment. Each subject driver was asked to drive in the simulator for ten runs from the start point.

3.35 Wireless Communication

Recent innovations in wireless networking technology have brought low cost, high bandwidth and low latency wireless networks to the consumer. Services like Vodacom's HSDPA, iBurst, Sentech's My Wireless and up and coming services like Telkom's WIMAX now enable permanent high-speed Internet connections. Most of South Africa's urban regions are already covered by at least one of the broadband wireless services, with rural coverage anticipated with the launch of WIMAX and other 4G wireless technologies.

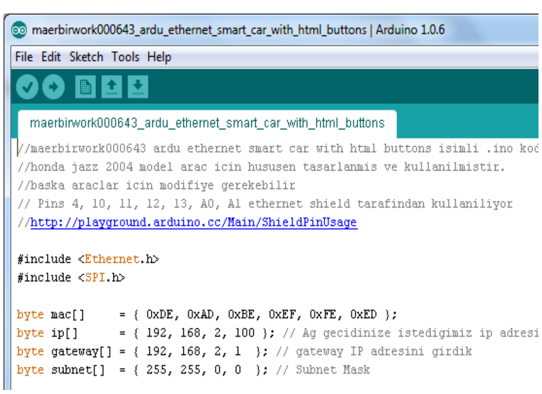

Fig.10. Arduino compiler window

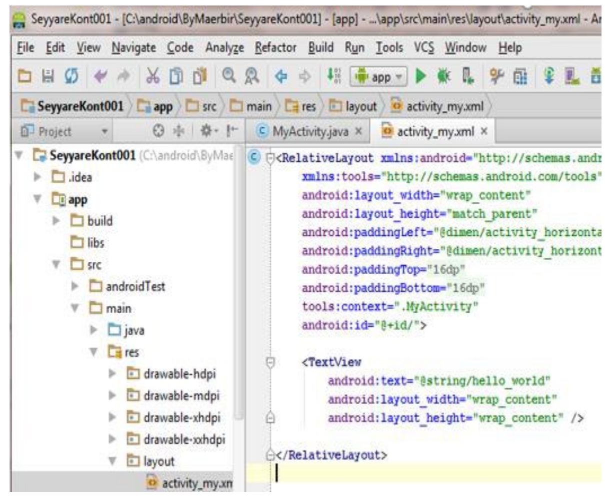

Fig.11. Android compiler window

IV. CONCLUSION

This study has explained the mechanisms of driving simulation technology by describing each system in the architecture. The human perceptual system was also briefly explained since the purpose of a driving simulator is to evoke a desired response from that system while imitating the driving experience. Current state-of-the-art simulators are also presented, together with their most important characteristics and typical uses. These state-of-the-art systems aim for the highest level of fidelity by providing highly immersive set-ups with full vehicle mock-ups, a large field of view, and accurate vehicle dynamics models. The ability to create and control driving conditions and scenarios such as weather and traffic are also key. When using motion, these simulators also include well developed motion cueing algorithms that account not only for the limitations of the human perceptual system but also for the boundaries of the motion system. Static simulators can often be used in studies where the focus is not primarily closed loop control of the vehicle by a human driver, while motion simulators offer an increased scope of use, including analysis of chassis control and autonomous features.

It is important to highlight that the three of the most important benefits of driving simulation are the safety for subject drivers and other road users, the reduction of time in design phase, and the ability to reproduce a variety of controlled scenarios and conditions. In addition, it is possible to foresee positive prospects for expanded driving simulation use. The increasing momentum of autonomous and active control systems means that more virtual validation of these systems will be required in the future.

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