



Driving Simulator Laboratory

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1 Introduction

Housed at the Virginia Campus of The George Washington University, the state-of-the-art Driving Simulator Laboratory is used to conduct vital vehicle and driving behavior research. The primary goal of this research is to avoid crashes and collisions on the road. This laboratory allows the Center for Intelligent Systems Research (CISR) to perform driving experiments in a safe and controlled laboratory setting.

Using a vehicle donated by General Motors Corporation, the simulator will be used to conduct research with the primary goal of avoiding crashes and collisions on the road. The lab allows for experiments on the impact of a wide range of factors, including drowsiness and road or traffic distractions. This data is then used to develop warning systems for potential hazards that might lead to crashes. In addition, the simulator could be employed in a number of other studies, such as:

- Measuring the distraction potential of future in-vehicle intelligent transportation systems,
- Determining the impact of road design on driver behavior, and
- Developing cognitive models of human driving behavior.

The driving simulator environment is ideal for this research because it provides an environment that is both safe and replicable. The simulators can safely measure driver reaction to unsafe and even life-threatening situations. Moreover, simulators can be used in carefully controlled experimental studies, in which the experimental variables are isolated from other factors that might influence driver performance. New driving scenarios are easily created and allow the specification of an arbitrary sequence of tasks, events and performance measurement intervals. The simulator also allows the collection of data on rare but important situations in a short time frame.

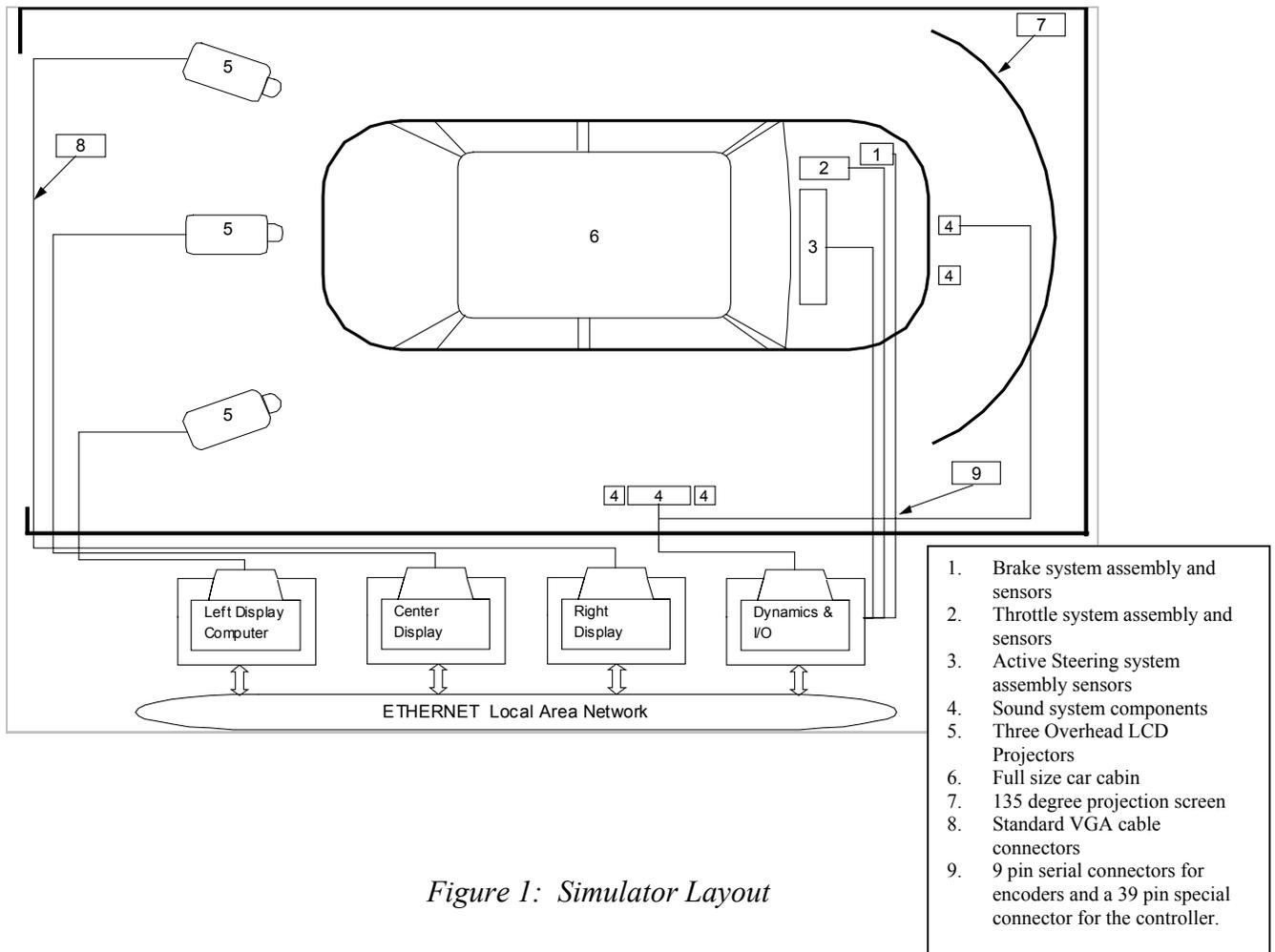
Our full-featured simulator is able to provide a life-like driving experience. The visual display is a curved screen with 135-degree wide-angle field of view. In addition, auditory feedback is provided through stereo components. The steering wheel produces an authentic feeling of road grip through a generated counter torque. A validated vehicle dynamics program governs the behavior of the vehicles in the simulation.

The Driving Simulator Laboratory performs comprehensive data collection, including eye-tracking data. The data includes the complete vehicle dynamics, as well as the steering angle, throttle position, and brake position. In addition, an eye-tracking system provides accurate measurement of the driver's focal point of attention, pupil size, blink rate, and the time that eyes stay shut during blinks.



2 Overview of Simulator

The following overview of the simulator provides general descriptions of four main aspects. The section, *Simulator Layout*, describes the physical set up of the Vehicle Simulator Laboratory. The next section, *Functional Description of the Simulator*, describes how the major components of the simulator work together during a simulator session. Then *Eye Tracking System* provides an overview of that component. The final section *Simulator Output* describes the data acquisition capabilities.



2.1 Simulator Layout

The physical layout of the simulator, shown in Figure 1, is comprised of sensors to detect driver behavior, visual and auditory feedback mechanisms, and a computer network. Sensors are located inside the vehicle to detect the driver's braking, steering, and throttle control signals.



Driver feedback is provided with three LCD projectors, a 135-degree projection screen, steering wheel torque, and a sound system. Four networked computers drive the simulation. Three computers generate images for the simulation, each one controlling one of the LCD projectors. The fourth computer generates realistic vehicle dynamics for the simulation, and it performs data acquisition.

2.2 Functional Description of Simulator

The simulator contains numerous functional blocks that interact during a simulation. The relationship between these components is shown in Figure 2. The core of the simulation is provided by the control inputs generated by the driver, and detected with the steering, braking, and throttle sensors. The vehicle math model uses a complex and realistic algorithm to calculate the impact of control signals on the vehicle dynamics.

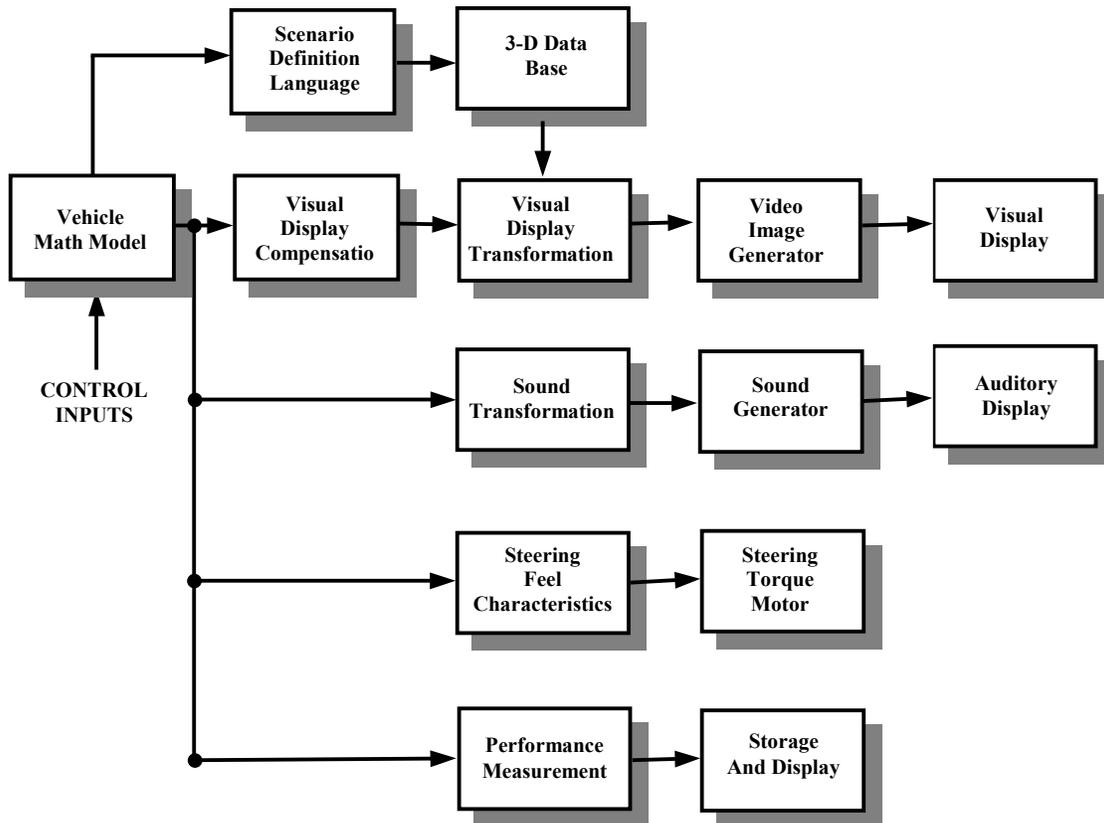


Figure 2: Functional Block Diagram of the Vehicle Dynamics Simulator

The visual display uses the vehicle dynamics and a simulation scenario to generate the images in a simulation. A scenario, defined with the Scenario Definition Language, guides a simulation by specifying the roadside environment, the presence of other vehicles, and the



roadway geography. The dynamics from the vehicle math model are immediately displayed visually. Then, the simulation scenario is consulted and complex visual objects retrieved from a 3-D database, in order to generate the next complete video image. This image is used by a video image generator to update the visual display.

The driver also receives auditory and haptic feedback. The auditory feedback is produced by three modules that perform sound transformation, generation, and output. Haptic feedback is produced by a module that takes as input the vehicle handling characteristics and uses a steering torque motor to produce lifelike handling.

A performance measurement module takes the experimental measurements. This data can be stored as a file and displayed during the simulation run. The details of the data acquisition are described in the final section.

2.3 Eye Tracking System

The simulator lab is also equipped with a state of the art eye tracking system. The system accurately measures both where a driver is looking and the state of the driver's eyes, i.e. the blink rate, pupil size, and blink closure time. The Model 501 Head Tracking System, manufactured by Applied Science Laboratories, has specifications listed in Table 1.

Table 1: Model 501 Eye Tracking System Specifications

Measurement	Pupil Diameter Eye line of gaze with respect to head tracker source reference frame, and surfaces that are stationary in that frame
Allowable Measurement Field	Essentially unlimited due to free head motion
Allowable Eye Movement	Along the horizontal axis, 50 degrees. Along the vertical axis, 35 deg or more depending on optics placement and eyelids
Precision	Better then 0.5 deg
Accuracy	Spatial error between true eye position and computed measurement is less then 1 deg. Errors may increase to less then 2 deg in the periphery of the visual field
Eyeglass and Contact Lens Acceptance	Most are accepted
Ambient Illumination	Complete darkness to moderate illumination resulting in pupil diameters greater then 3mm.
Sampling and Output Rate	60 Hz, 120 Hz, and 140 Hz



The functional diagram for the eye tracking system is listed in Figure 3. The eye tracker optical components consist of an eye camera, a scene camera and an infrared illuminator. These optical components are attached to the head by mounting on a helmet or a headband.

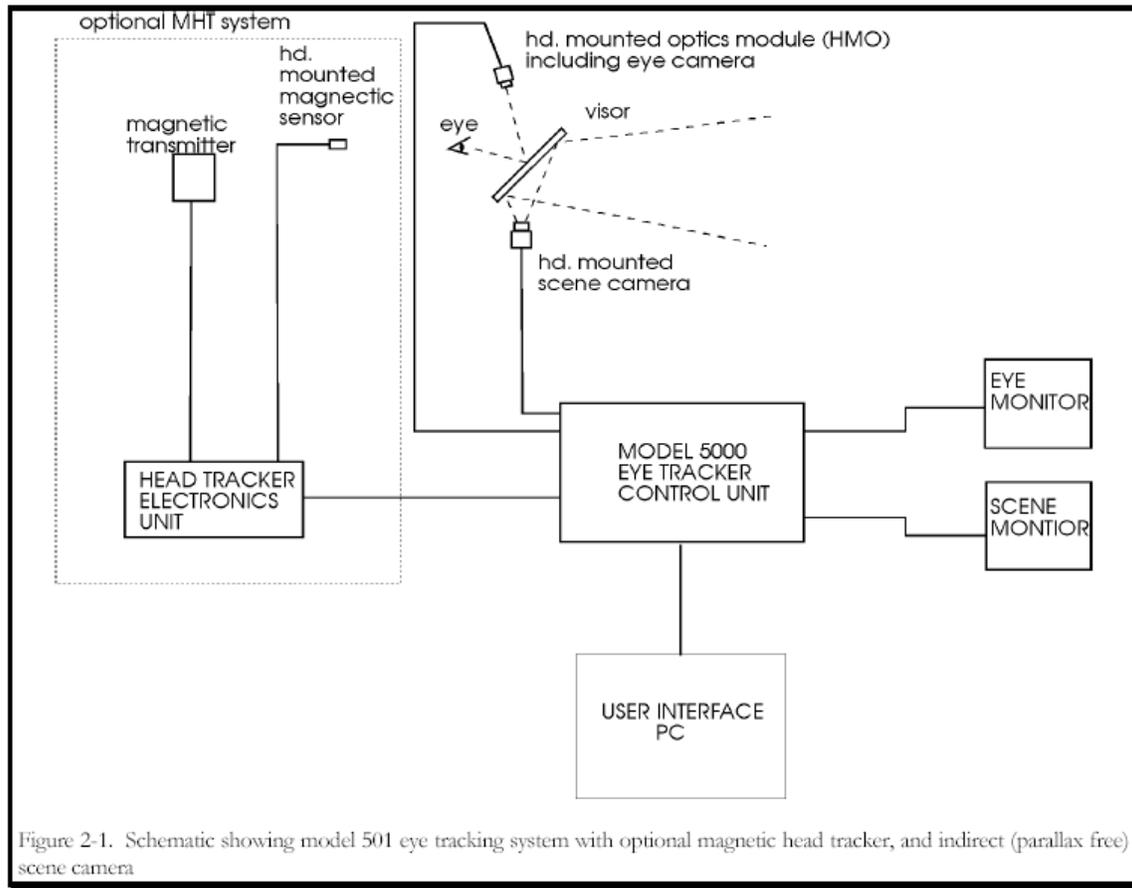


Figure 3: Eye tracking system (from the ASL Eye Tracking System Documentation)

The beam from the infrared illuminator shines on the eye. An optical system focuses an image of the eye onto a solid-state video sensor (eye camera). The illumination beam with the eye image is reflected from the visor, because it is coated to be reflective in the near infrared region and translucent to visible light. Simultaneously, a scene camera captures the image in front of the driver.

The Model 5000 control unit processes the eye camera signal to extract the pupil and reflection of the light source on the cornea. It then computes both the pupil diameter and the line of gaze. The images from the system are displayed on two monitors. One monitor contains a video image of the eye with pupil and corneal reflection outlines. The other monitor displays the driver's eye line of gaze, by displaying cross hairs superimposed on the scene video image. A PC contains the user interface to the eye tracker software and a digital data-recording device.



2.4 Simulator Output

A wide array of data is produced by the simulator and stored for research purposes. This data is recorded both by the simulation software and the eye tracking software. Both sources can record data to ASCII files. Each record in the file is a snapshot of the current vehicle and driver state. The interval between snapshots can either be specified in seconds or feet.

The system also creates both a summary file of the events that occurred during the simulation run and snapshots of the vehicle and driver performance. Events include time to collision data, red light running, speeding, traffic tickets, pedestrian hits, and other driver errors. The snapshots include the following statistics:

- Elapsed time
- Distance traveled
- Longitudinal acceleration
- Lateral acceleration
- Longitudinal velocity
- Lateral velocity
- Lateral lane position
- Vehicle curvature
- Road curvature
- Steering wheel angle
- Steering wheel velocity
- Throttle input
- Brake pedal force
- Yaw rate
- Crash type

The eye tracking software accurately measures both where a driver is looking and the state of the driver's eyes. Thus, its data includes the driver's focal point of attention, blink rate, pupil size, and blink closure time.



3 Ex-Vehicle Hardware

At the core of the computer hardware used for the simulator is the network of computers. The computers require additional internal boards for the simulation and a projection system. This section describes these ex-vehicle hardware components.

3.1 STISIM Minimum Hardware Requirements

The STISIM simulation requires four computers, and the eye tracking system requires one. Three of the computers, shown in Figure 4, generate the video images during the simulation, for the three projectors. The fourth computer, shown in Figure 5, generates the vehicle dynamics for the simulation.



Figure 4: Video Image Generation Computers

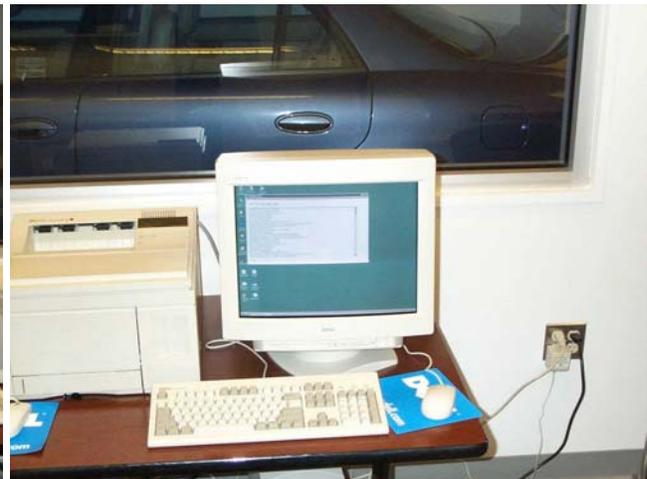


Figure 5: Dynamics Computer

The minimum requirements are that these computers use Intel Pentium processors running at 200 MHz or faster. In addition, they require 100 megabytes of free disk space, 128 megabytes of random access memory, one free parallel port, and a multiple frequency VGA monitor.

3.2 Additional Boards for STISIM

The simulator requires additional boards to be installed in the four STISIM PC's. These requirements are summarized in Table 2.



Table 2: PC Card Requirements

	<u>Type</u>	<u>Center</u>	<u>Left</u>	<u>Right</u>	<u>Dynamics</u>
VGA Card	PCI	Yes	Yes	Yes	Yes
3D Fx Graphics Card	PCI	Yes	Yes	Yes	No
Network Card	PCI	Yes	Yes	Yes	Yes
Sound Card	PCI	Yes	No	No	No
Optical Encoder Card	ISA	No	No	No	Yes
Digital to Analog Card	ISA	No	No	No	Yes

All the machines require a VGA card. However, the display machines specifically require a video card with 3D Fx Voodoo chipset built into it. Our system has the *Quantum 3D Obsidian Release 5.0 card* with a maximum resolution of 1024 x 768 pixels.

The computers that run the simulator need to communicate with each other during the simulation. Consequently, the vehicle dynamics computer and the three display computers are networked together. Each machine contains a *100 Base-T Ethernet card*, which is connected to an Ethernet hub. Although the network is connected to the Internet, the machines are on an externally unaddressable subnet to prevent malicious attacks on the computers. The connection to the Internet is used only to download software patches.

The auditory feedback for the system is produced by the center display machine, which therefore requires a sound card. The sound system uses a *Sound Blaster PCI card* and a speaker system consisting of 4 speakers and a sub woofer.

Three quadrature optical encoders read the steering, brake and throttle control inputs. These encoders are connected to a *Metrabyte M5312-4 interface board* in the dynamics computer through RS-232 nine-pin serial connectors. This board provides four connections, called axes, for optical encoder input. The steering, braking and throttle inputs are each connected to an individual axis, while the fourth axis is used as a backup.

The *Computer Boards Inc. Model CIO-DDA06/12 board* in the Dynamics computer handles digital input and analog output signals. This 12-bit digital to analog converter is equipped for six analog outputs and 12 digital inputs. The digital input signals are used for



inputting user responses to horn, turn signal and divided attention tasks, while the analog output signals are used to send voltages to the active steering system.



Figure 6: The 135-degree display

3.3 STISIM Display

The visual display scene is projected on the curved screen through three PROXIMA projectors, to create a 135-degree wide-angle field of view. This display is shown in Figure 6. Table 3 contains the complete specifications for the Proxima DP9250 projectors.

Table 3: Projector Specifications

Model	Proxima DP9250
Display Technology	1.3" polysilicon TFT LCD x 3 with micro lens
Resolution	XGA 1024 x 768
Computer Compatibility	IBM PC, PS/2, Pentium and compatibles, SUN, SGI, IBM, DEC, and X-Terminals
Video Compatibility	NTSC, PAL, PAL-M, SECAM
Sources	2 computers, 2 audio, 2 video, or 1 s-video
Dot Clock	160 MHZ
Number of Colors	16.7 million
Projection Distance	4.6 ft to 35.4 ft
Lamp	150 watt uhp
Audio	2W + 2W RMS
Lens	Power Zoom and focus lens, 13:1 ratio
Aspect Ratio	Std: 4:3 – Wide: 16:9



3.4 Eye Tracking Hardware

The hardware for the Eye Tracking System is display in Figure 7. The major components are the Interface PC, the control unit, the head mounted optics, the head tracking hardware, and the monitors.

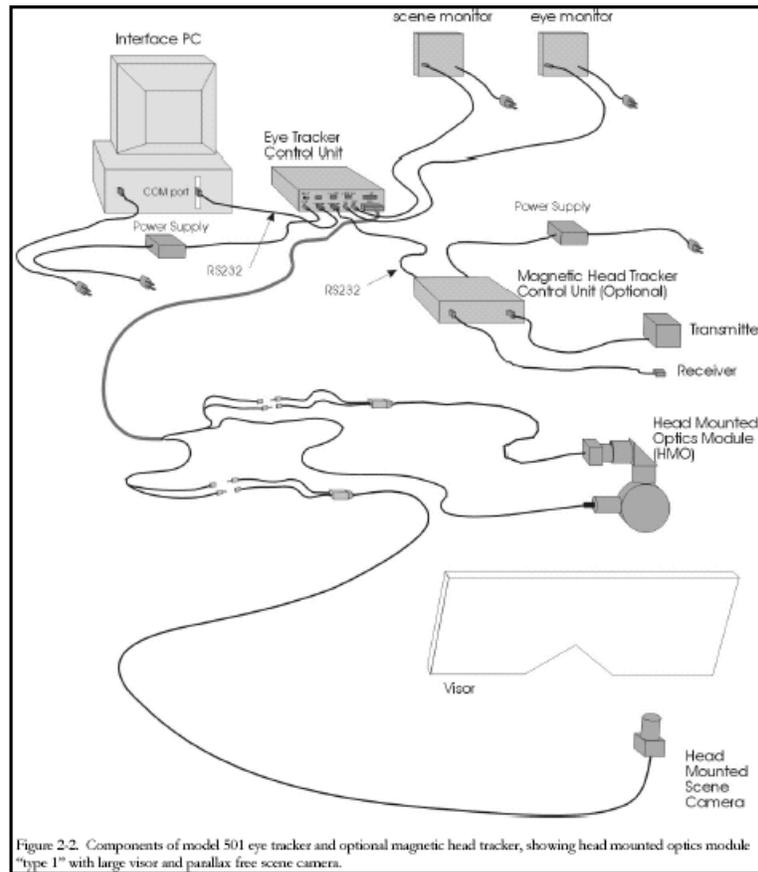


Figure 7: Eye tracking hardware (from the ASL Eye Tracking System Documentation)

The interface PC provides the user interface to the eye tracking system and the data recording devices. It must be an IBM compatible Pentium based PC with a speed of 200 MHz or faster, with free serial and parallel ports, and a VGA monitor. It can run either Windows 95, Windows 98 or the Windows NT operating system. It is connected to the control unit with a RS-232 serial cable.

The Model 5000 Eye Tracking System Control Unit houses the processing board that receives video from eye and scene cameras. Its image processing function recognizes features in the video eye image and computes line of gaze. It receives feedback from the head tracker and uses the head position data to compute the line of gaze with respect to fixed surfaces in the environment. As well as sending output to the Interface PC, it also superimposes feedback outlines, cross hairs, and cursors on the eye and scene monitors.

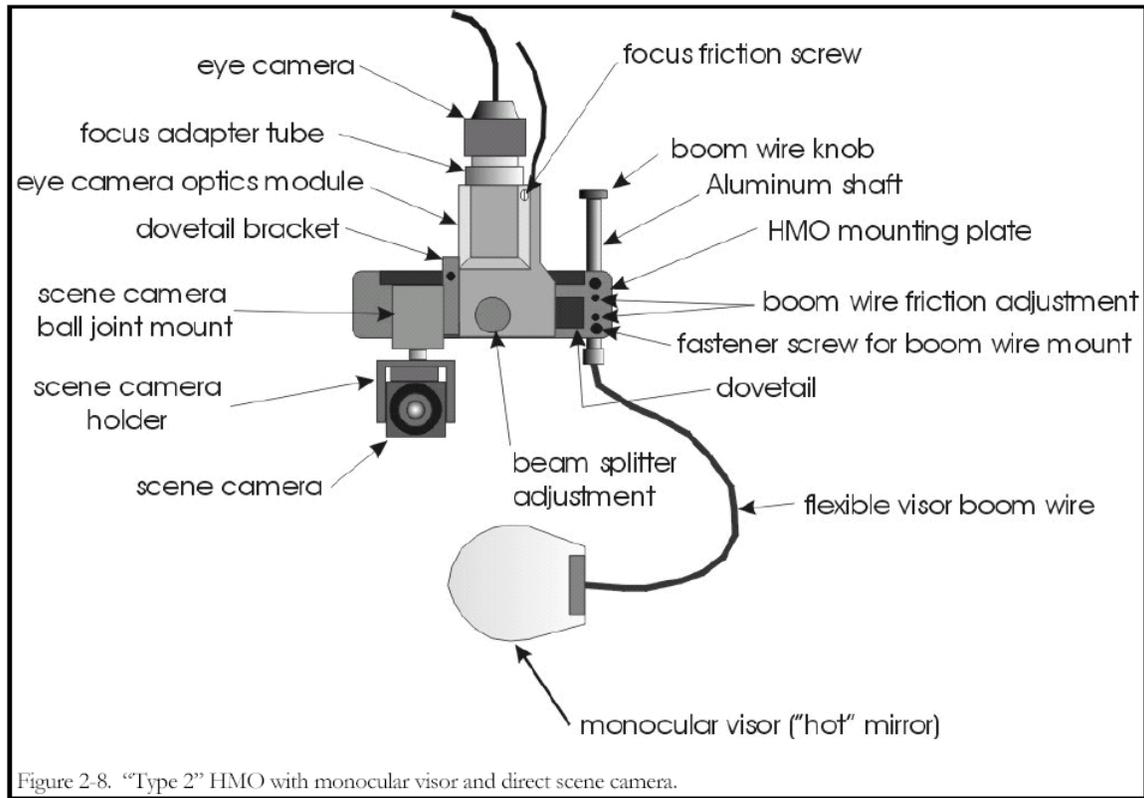


Figure 8: Head mounted optics (from the ASL Eye Tracking System Documentation)

The head-mounted optics system is depicted in Figure 8. This system consists of an eye camera, an infrared illuminator, a scene camera, and a monocular visor. These components are mounted on a headset or helmet, and can be adjusted for an individual driver.

The Magnetic Head Tracking (MHT) hardware is comprised of a control unit, a transmitter, and a receiver. The MHT accurately determines head position and orientation. This Ascension *Flock of Birds* position and orientation measurement system has specifications as listed in Table 4. The head position is measured in six degrees of freedom and at a distance of up to 28 inches from the reference source. A magnetic transmitter gimbal mount and laser wand are used to quickly define points on surfaces in the environment to facilitate setup for the MHT.



Table 4: Ascension Flock of Birds Magnetic Head Tracking Specifications

Transmitter	3.75" cube mounted inside enclosure
Sensor	1" x 1" x 0.8" cube
Position Range	'+/- 48" in any direction
Angular Range	+/- 180 deg azimuth & Role +/- 90 deg Elevation
Static Position Accuracy	0.1" RMS averaged over the translational range
Static Angular Accuracy	0.03" @ 12"
Angular Resolution	0.5 deg RMS averaged over the translational range
Update Rate	100 measurements/sec
Outputs	X, Y, Z positional coordinates and orientation angles, rotation matrix, or quaternion
Interface	RS232: 2400 to 115200 baud RS485: 57600 to 500000 baud

In addition, the Eye Tracking System uses two monitors. One black and white monitor is used for displayed the processed video from the eye camera, and the other monitor is used for displaying the video from the scene camera.



4 In-Vehicle Hardware

This section details the in-vehicle hardware. The engine of the vehicle was removed to allow space underneath the hood. This hardware is required to measure the three major driving operations - steering, braking and accelerating. A view of the hardware under the hood of the vehicle is shown in Figure 9.



Figure 9: In-Vehicle Simulation Hardware

4.1 Steering system

The steering system performs two functions; it measures the steering wheel angle and produces a feeling of road grip in the steering wheel through a generated counter torque. The system consists of a DC motor connected to a pulley through a toothed gear. The pulley is mounted on a shaft, which is connected to the steering column through an adjustable universal joint. The motor and pulley assembly is housed in a U shaped bracket, which is mounted on a platform under the hood. A potentiometer sensor is attached to the other end of the motor armature. This sensor measures the angular displacement of the armature shaft, which is the same as that of the steering wheel. The potentiometer sensor is connected through a RS-232



nine-pin serial cable to the computer running the vehicle dynamics program. The DC motor is controlled by control signals generated by the vehicle dynamics program, through a control module mounted on the same platform to the left of the DC motor. The motor generates a counter torque in accordance with the road scenario and vehicle dynamics parameters. This torque is transmitted through the belt and pulley to the steering wheel so the driver will have a realistic feeling of road grip in the steering wheel. A special power-supply unit supplies power to the controller and motor. The controller is connected through a 39-pin connector to the computer running the vehicle dynamics program. A clear view of the connection of the DC motor, the belt and pulley, and the universal joint that connects the pulley to the steering shaft is shown in Figure 10. While a wider view for the whole steering system components is shown in Figure 11.



Figure 10: Partial View of the Steering System

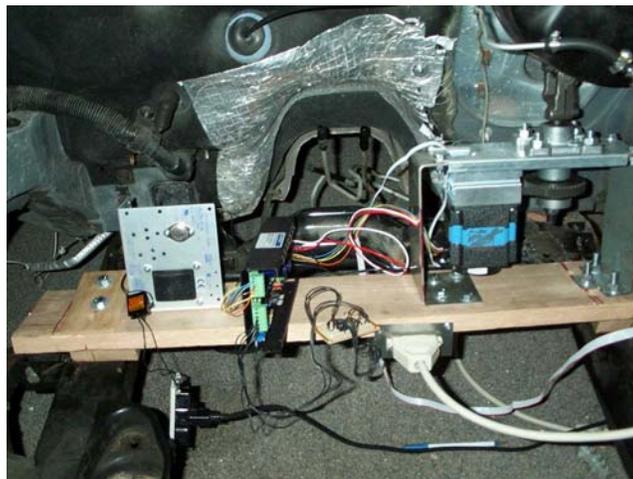


Figure 11: Full View of the Steering System



4.2 Braking system

A potentiometer sensor is installed to measure the distance traveled by the brake pedal and transmit it to the computer running the vehicle dynamics program through a 9-pin cable. The sensor is attached to the pinion shaft of a rake and pinion assembly so that it rotates with the pinion shaft. The rake is mounted on a solid cylinder, which slides in a hollow aluminum cylinder. The inner solid cylinder is connected to the piston of the master cylinder of the vehicle braking system by a steel rod. Pressing and releasing the brake pedal will result in the sliding motion of the rake, which will be translated into circular motion of the pinion to which the sensor is attached. The sensor is housed in a hollow aluminum casing. The whole assembly is welded to the end of the vehicle master cylinder at the end. In order to have a realistic feel of the brake pedal, one of the wheel cylinders is connected to the master cylinder, which will develop hydraulic pressure in the cylinder and felt by the driver when tapping on the brake pedal. The components of the braking system are shown in Figure 12.



Figure 12: Components of the Braking System

4.3 Accelerating System

A potentiometer sensor is coupled with the butterfly valve shaft in the vehicle throttle body. The sensor is housed in a specially designed housing bolted to the throttle body. Pressing on the accelerator pedal will open the butterfly valve and rotate the potentiometer, which sends this information to the vehicle dynamics computer through a 9-pin cable. As the vehicle original throttle body is used, the feel of the gas pedal will be exactly the same as that of the actual



driving. The throttle body is bolted to the vehicle battery compartment under the hood. The components of the accelerating system are shown in Figure 13.



Figure 13: Components of the Accelerating System



5 Software

Software for the simulator is either associated with the STISIM simulation software or the ASL Eye Tracking System. The following sections provide the details of these packages.

5.1 STISIM Simulation Software

The simulator, based on STISIM by System Technology, Inc, is widely used by industry and the Department of Transportation for vehicle and driving behavior research. This software was originally developed for the National Highway Traffic Safety Administration in the 1980's and was commercialized later. The same vehicle dynamics model is being used for the roadside safety design concept of Integrated Highway Safety Design Module by the Federal Highway Administration's Roadside Safety Design division.

Two packages form the core of the simulator. Three computers run the main simulation program, STISIM Drive, which generates the visual and auditory feedback. The version currently in use is STISIM Drive Build 1.02.07. The vehicle dynamics program, VDANL Drive, is installed on a fourth computer. The math model in this program allows for user-specifiable, realistic steering and speed control characteristics. The version in use is VDNL Drive version 6.0.30. Both packages require the operating system Windows NT with service pack 3 or later.

In addition to these packages, additional data files are developed with STISIM's Scenario Definition Language (SDL). SDL allows the user to create driving scenarios by specifying an arbitrary sequence of driving tasks, events, and performance measurement intervals. Approximately ten thousand events can be programmed in a simulation run. In addition, to give the graphics a more realistic look, figures created in 3D Studio software can be imported as static objects and displayed during the simulation.

5.2 Eye Tracking Software

The Eye Tracking System contains a number of software packages. These packages can run on Windows 95, Windows 98, or Windows NT. The *EYEPOS* package with *EYEHEAD* integration software is used to record simulation data and operate the eye tracking and magnetic head tracking controllers. The *EYENAL* package provides data analysis software for exploring simulation results. The *FIXPLOT* package is used to plot eye scan paths. In addition, there is a *CONVERT* utility that converts binary output data files to ASCII and Microsoft ACCESS formats. The *EYEPOS* and *EYENAL* packages are version 5.33, and the *FIXPLOT* package is version 2.0.