Design and Integration of a Driving Simulator With Eye-Tracking Capabilities in the Computer Assisted Rehabilitation Environment (CAREN)

Harvey M. Edwards, III, B.S.
Rachel Markwald, Ph.D.

Naval Health Research Center

Report No. 14-9I supported by Defense Health Program 6.7 Funding under Work Unit No. 61030.

Naval Health Research Center

140 Sylvester Road

San Diego, California 92106-3521

INTRODUCTION

The Computer Assisted Rehabilitation Environment (CAREN; Motek Medical BV, Amsterdam, The Netherlands; Figure 1) is an immersive virtual environment and motion analysis laboratory designed for interactive rehabilitation and research of human performance in a controlled and repeatable environment. The Department of Defense uses the CAREN system for clinical rehabilitation and research at four locations: Naval Health Research Center (NHRC), Walter Reed National Military Medical Center, Brooke Army Medical Center, and the National Intrepid Center of Excellence. At NHRC, the CAREN is used to conduct research for the advancement of treatment and rehabilitation practices in the CAREN and other interactive environments. NHRC creates and tests accelerated rehabilitation programs, and conducts physical and cognitive performance testing under virtual conditions relevant to the warfighter.

Figure 1. Computer Assisted Rehabilitation Environment (CAREN).

The CAREN requires control software in order to manipulate and monitor the hardware components, activate events, record information, and create virtual scenarios. The CAREN D-Flow control software (Motek Medical) allows the operator to create, modify, and operate virtual scenarios. It incorporates different modules from which to manipulate and monitor the hardware components, activate events, and record information. The ideal driving simulator for NHRC would include a variety of easily modified road courses, and it would have the ability to collect data for research purposes, simulate realistic automobile movements using the motion base platform, and integrate an eye-tracking system. While the D-Flow software is capable of controlling the system and creating driving scenarios, it does not contain a variety of easily modified road courses, has no module to simulate realistic automobile movements during driving, and does not allow for eye-tracking capabilities.

It was determined that the driving simulator software would need to run on a separate computer network, rather than that of the D-Flow software, using a Phidget (Phidgets Inc., Calgary, Canada) to bring analog signals to the D-Flow software for platform motion control. Pixelwarp Evo software (Florida Music Technologies Inc., USA) would be required to warp and blend the video for the CAREN's 180 degree curved screen. In order to satisfy all the requirements for an NHRC driving simulator, STISIM Drive software (Systems Technology, Inc., Hawthorne, CA)

Figure 2. NHRC custom-designed driving simulator.

was chosen as the control software for the driving simulator. This software is specifically designed for driving simulation research and has been used for this purpose by universities, government agencies, medical facilities, training centers, and corporations. STISIM software is also "open software," meaning it is customizable, allowing for integration of hardware like eye-tracking systems. The faceLAB 5 eye-tracking system (Seeing Machines, Tucson, AZ) was selected as the eye-tracking platform for the driving simulator. This software was also paired with EyeWorks software (EyeTracking, Inc., Solana Beach, CA), which allows for advanced design, collection, and analysis of eye-tracking data. These systems work in combination with the STISIM Drive software to allow for seamless data collection when synced with Network Time Protocol (NTP) software (http://www.ntp.org/). The driving simulator cab was custom designed and built in house at NHRC using realistic braking and steering components. The Trackstar 6000 GT system package (Extreme Competition Controls, Inc. [ECCI], USA) was integrated into the driving cab for the simulated steering, accelerating, and braking. The driving cab itself is built from metal tubing and designed to bolt safely onto the motion platform frame.

The purpose of this paper is to report the methods for designing and integrating this driving simulator into the NHRC CAREN system.

METHODS

Pixelwarp Evo Software

Pixelwarp EVO is a software program that deals with geometric correction and edge blending of full-screen real-time gaming applications. The software takes a projected display and manipulates control points in order to align the image on the screen (Figure 4). With the

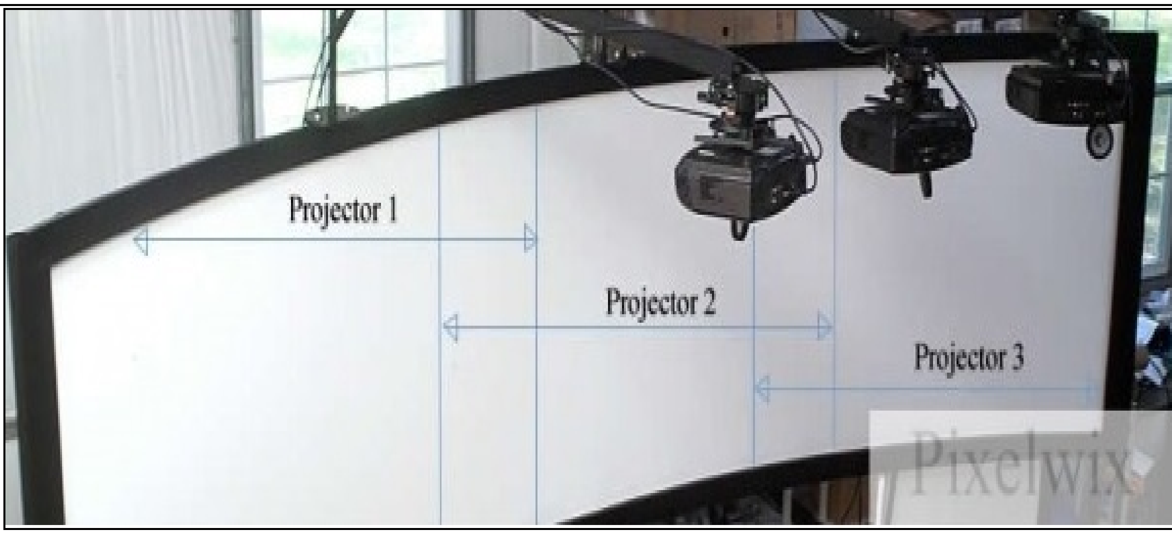


Figure 4. Pixelwarp EVO warping and blending technique.

Pixelwarp software and a Matrox TripleHead2Go multi-display adapter (Matrox Graphics Inc., Quebec, Canada), the driving simulator video can be split into three outputs, one for each projector, then warped and blended seamlessly over the CAREN's 180-degree curved screen at a resolution up to 5760 × 1080. This video is connected to the three CAREN projectors via the DVI inputs (Figure 5).

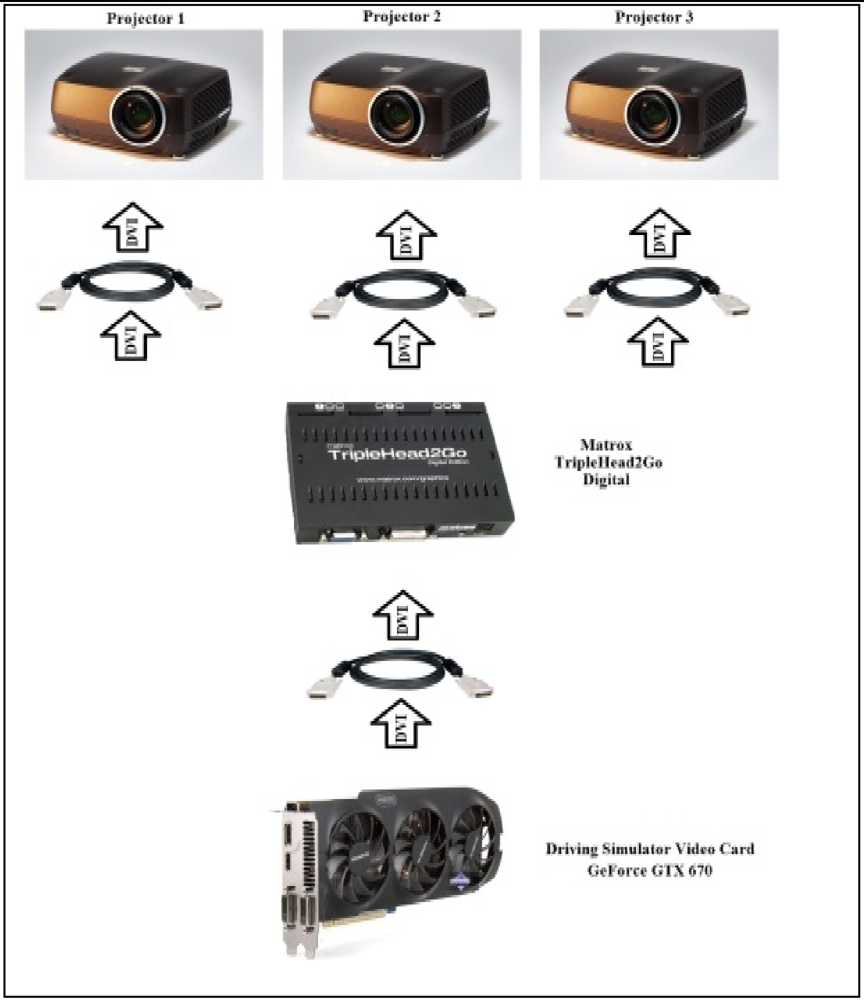


Figure 5. Driving simulator video flow diagram.

STISIM Drive Software

STISIM Drive is a programmable and fully interactive virtual reality driving simulator engineered to take advantage of cutting-edge computer technology. It has more than 80 ready-to-run driving scenarios that present diverse driving situations, customizable roadway environments, and an extensive library of roadway objects. The system also allows for user-definable data collection.

STISIM Drive has an Advanced Vehicle Dynamics Module (VDANL Drive). This module gives six analog output signals that can control the six-degrees-of-freedom motion platform in the CAREN system in order to simulate real automobile movements during driving. This is achieved by installing in the driving simulator computer a PCIM-DDA06/16 6-channel, 16-bit analog output board with 24 digital I/O (Measurement Computing Corporation [MCC], Norton, MA), which can control swaying, heaving, surging, pitching, yawing, and rolling on the CAREN motion platform.

A significant amount of hardware is required to bring this signal to the D-Flow computer. A 37-pin shielded cable (MCC model C37FFS-5) is connected to the PCIM-DDA06/16 card then to a 37-pin universal screw terminal board (MCC model CIO-MINI37). The screw terminal board is then wired to the analog inputs in the model 1018 PhidgetInterfaceKit (Phidgets Inc., Calgary, Canada) I/O board. Once this is completed, the PhidgetInterfaceKit USB cable is connected to the CAREN computer in which the D-Flow software is installed (Figure 6). A simple application is then created in the D-Flow software connecting the analog signals from the STISIM Drive software to the inputs of the motion platform using expressions to adjust the analog signal ranges to coincide with that of the platform channel input ranges (Figure 7). When a driving simulation is loaded, the STISIM zeroes the analog outputs, simulating that the platform is in a neutral position. Upon starting the simulated drive, the platform is placed in the neutral position then manually engaged in D-Flow, enabling STISIM Drive to control the platform for simulated automobile movement.

The STISIM Drive software is also capable of stereo-quality sound. To integrate this audio into the CAREN system, a fiber optic Toslink cable is connected from the driving simulator computer to the CAREN audio system.

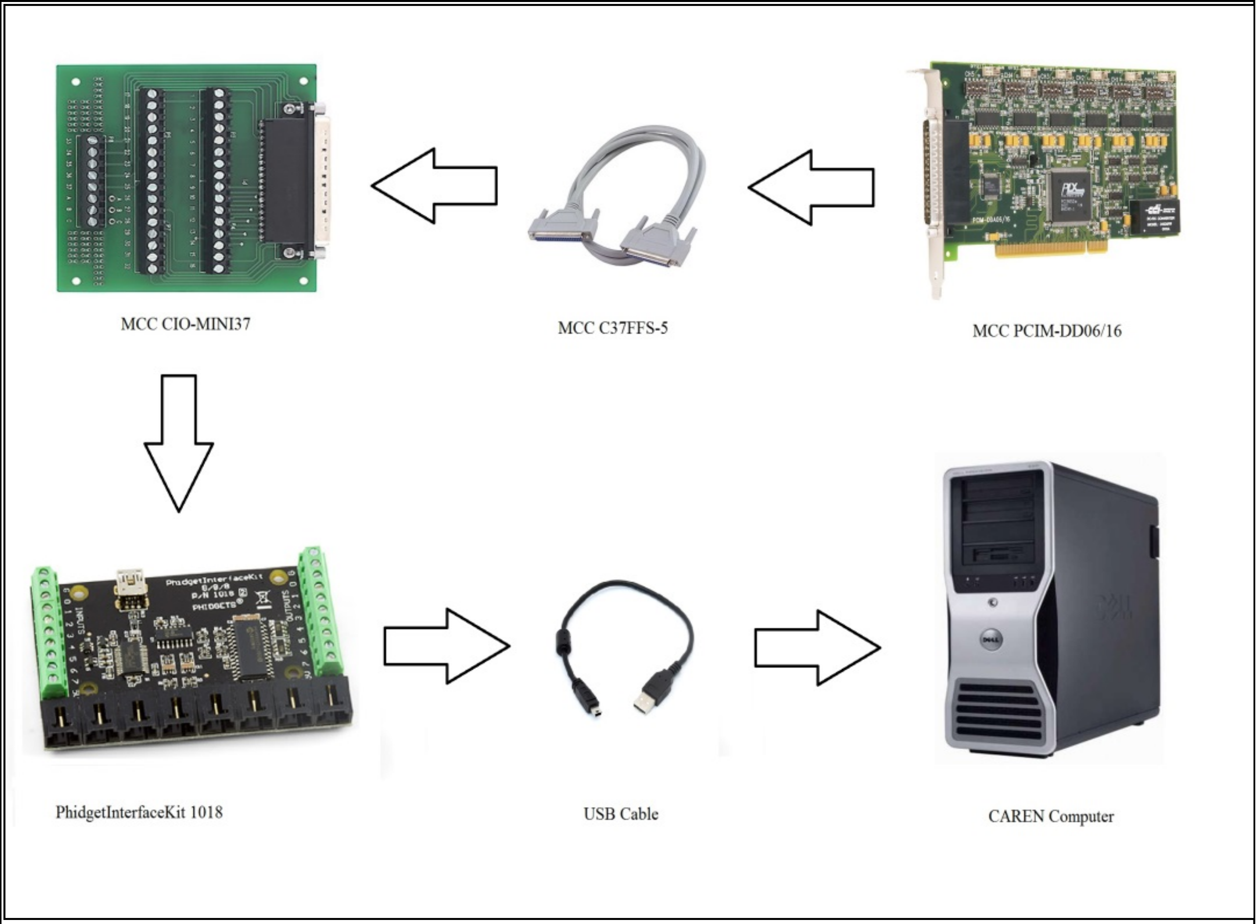


Figure 6. Driving simulator analog signal flow diagram.

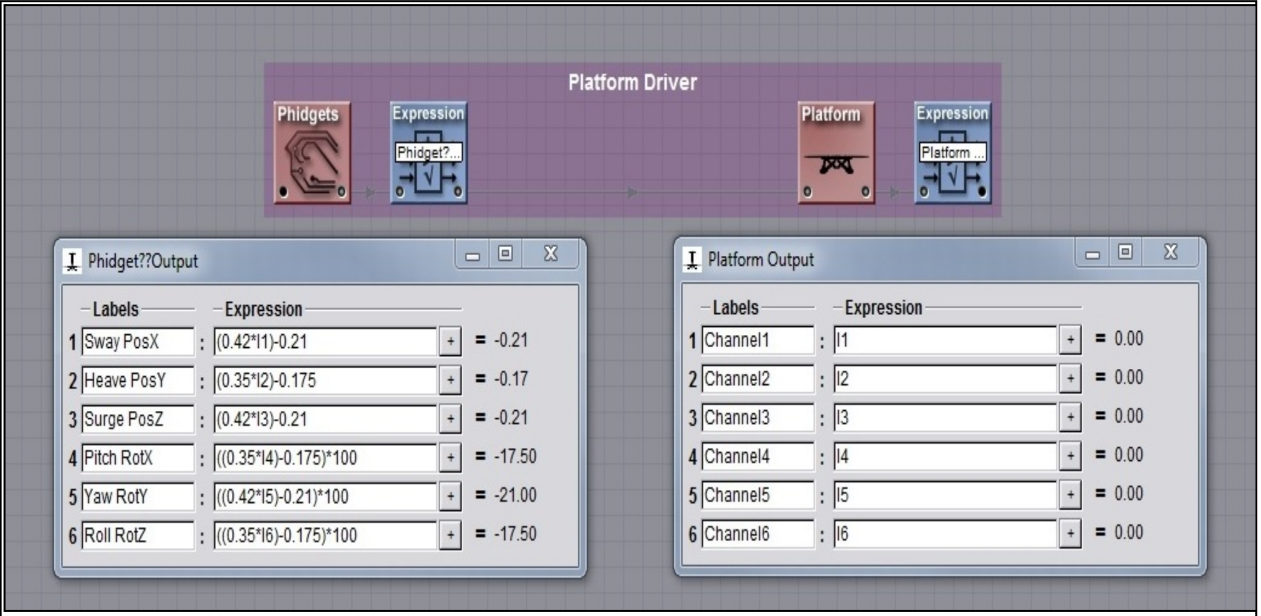
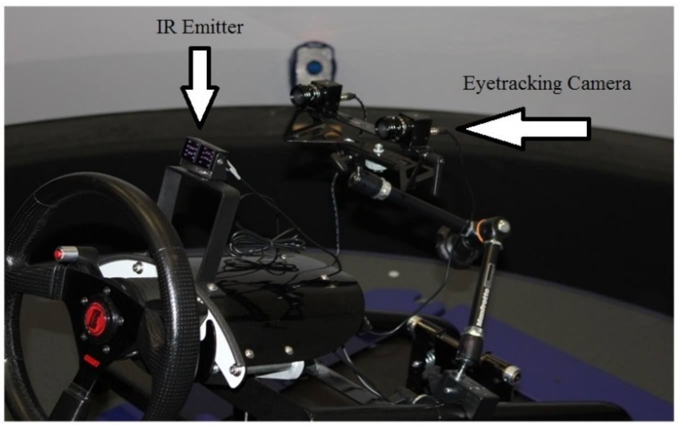


Figure 7. D-Flow driving simulator motion control application.

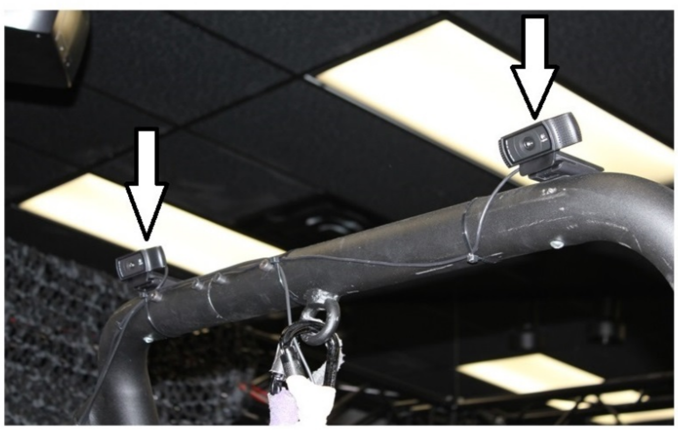
faceLAB 5 System and EyeWorks Software

The faceLAB 5 eye-tracking system (Figure 8) was chosen as the hardware/software package to collect eye-tracking data. This system can use either one or two eye-tracking cameras to collect data. Each eye-tracking camera requires its own computer for real-time data collection. An IR emitter is used in conjuction with this system to allow for eye tracking in low light conditions. This system has the ability to accurately capture an abundance of data, including head and eye positions, gaze position, eyelid and lip behavior, and many other head and facial features.

The EyeWorks software is an add-on software package that is used with the faceLAB 5 eye-tracking platform. This sofware increases the data collection capablities and is fully customizable for the driving simulator system. In our system, EyeWorks software works with two webcams



FaceLAB5 Eyetracking System



EyeWorks Webcams

Figure 8. faceLAB 5 system and EyeWorks webcams.

and two faceLAB 5 stereoheads in order to obtain eye-tracking data for ~120 degrees of the screen (Figure 8). If the full range of the 180 degree screen is of interest, then an additional stereohead would be required. All stereoheads are linked together by using the Link function in EyeWorks. All webcams and stereoheads are calibrated with the software and take video of the 180-degree curved screen during testing. This video shows eye-tracking data overlaid onto the driving simulator onscreen video.

Driving Simulator Cab

The NHRC driving simulator cab (Figure 9) is designed using automobile seat height and distance-to-pedal measurments to resemble that of an acutal automobile. The frame is constucted from black-powder–coated steel tubing. The high-performance racing seat has an adjustable slide mount bracket and a five-point safety harness. The ECCI Trackstar 6000 GT system package for steering, braking, and acceleration is an all-steel construction with a black-powder coat for durability. The pedal unit and seat position are adjustable to allow for various driver heights. The ECCI Trackstar 6000 GT steering is fully ball-bearing suspended and free from friction. The fluid damped steering system allows force and velocity of wheel movement to respond at a minute level. The damping effect does not limit subtle corrections of steering line, but it does increase proportionately with velocity of wheel movement. Quick, extreme movements are resisted, while slow and subtle movements are not. The result is realistic simulated wheel movement stabilization. The steering wheel also has paddle shifters and multiple buttons that can be programmed to provide the driver with additional tasks while driving. The ECCI package also uses a next generation pressured mapped brake pedal or PMB-II, which provides pedal operation with the true feel of an automobile brake. The ECCI Trackstar 6000 GT interfaces with the driving simulator computer using a standard USB cable and is fully compatible with the STISIM Drive software. The driving cab is bolted directly to the platform frame of the CAREN using preexisting handrail mounts.

Driving Simulator and Eye-Tracking System Data Syncing

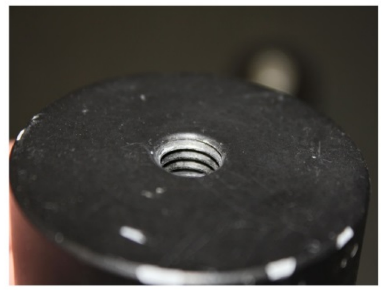
The driving simulator and eye-tracking system require a private network for communication and data syncing. The driving simulator/eye-tracking network uses an off-the-shelf network switch, and each computer in the system has its own network card dedicated specifically for network communication. Each computer is assigned a static IP and all have identical subnet masks. Static IP addresses are required for the NTP software to function properly. This software requires a host computer in order to sync all the remaining clocks in the network. This host computer is identified in the software via an IP address, thus it must remain static. In this network, the driving simulator computer is used as the host while the eye tracking and faceLAB 5 computers are set as client computers. Having the correct time and date on the host computer is not essential since all the client computers are synced to that time for data collection purposes. The NTP software will sync all the client computers to any date and time on the host computer, though having a correct date and time is recommended since this may be an important aspect of a research question and will also help reduce the risk of confusing data sets after testing.

This driving simulator/eye-tracking network has a total of four computers hardwired to the network switch: a driving simulator computer, an eye-tracking computer, and two faceLAB 5 computers (one for each eye-tracking camera). These computers all collect data during research studies, thus it is essential the computer times are synced for data processing. The eye-tracking computer and faceLAB 5 computers also use this network for communication in the software during calibration and testing.

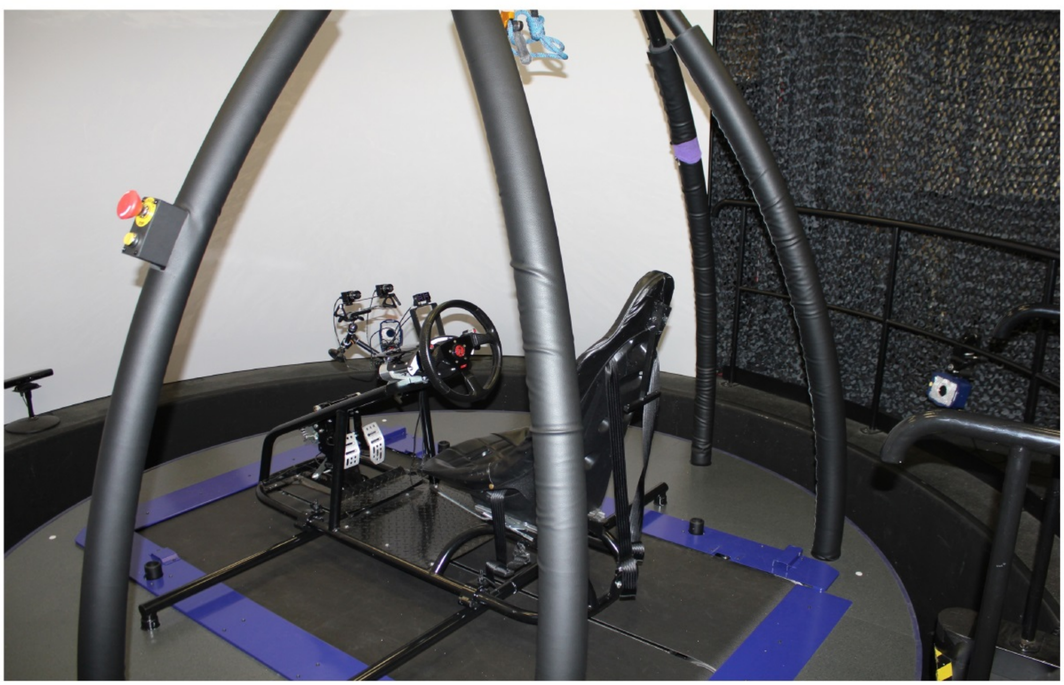
CAREN HANDRAIL MOUNT

DRIVING SIMULATOR CLAMP MOUNT

DRIVING SIMULATOR MOUNT WITH MOUNTING BOLT



DRIVING SIMULATOR THREADED MOUNT



DRIVING SIMULATOR SECURED ON MOTION PLATFORM

Figure 9. Driving simulator cab.

Safety

The driving simulator cab is installed on a platform that can produce sudden movements. It is essential that the cab is installed securely using all the required mounting hardware. Also, the safety harness must be properly fastened any time the platform is engaged and someone is driving the simulator.

RESULTS

STSIM software package

The STSIM software provides a number of automated outcomes that are generated as .txt files. Figure 10 provides a list of these outcomes. Summary measures offer an overview of the total number of mistakes that occurred during the scenario, while a case-by-case breakdown of each event is provided for a more detailed examination of each individual mistake. Rules identifying mistakes (e.g., cutoff points for speeding exceedances or tickets) can be easily modified in the program.

```
Driver mistakes:

Total number of off road accidents =      0
Total number of collisions =              0
Total number of pedestrians hit =         0
Total number of speed exceedances =       15
Total number of speeding tickets =        0
Total number of traffic light tickets =   0
Total number of stop signs missed =       0
Total number of centerline crossings =    0
Total number of road edge excursions =    0
Total number of stops at traffic lights = 0
Total number of correct DA responses =    0
Total number of incorrect DA responses =  0
Total number of DAs with no response =    0
Total run length (Drive T, X, Total T) =  531.72          40500         531.72
Total number of illegal turns =             0
Total number of low speed warnings =        0
Total number of high speed warnings =       0
Over speed limit (% Time, % Distance) =     25.74  29.33
Out of lane (% Time, % Distance) =          0.00   0.00

Individual mistakes (Time, Distance, Elapsed distance or object number, Elapsed time, Maximum value, Speed limit/Centerline):

Speed exceedance         92.74     6259.57     1279.20       14.40     89.14     88.00
Speed exceedance        115.33     8253.72     2032.62       22.05     94.74     88.00
Speed exceedance        148.88    11181.39        0.98        0.02     58.80     58.67
Speed exceedance        156.06    11573.43      328.08        5.02     74.32     58.67
Speed exceedance        182.97    13685.85      480.14        5.37     90.57     88.00
Speed exceedance        217.11    16630.63      203.36        2.30     88.71     88.00
Speed exceedance        229.19    17681.90      872.69        9.75     90.41     88.00
Speed exceedance        246.72    19228.40     4020.19       44.41     93.99     88.00
Speed exceedance        303.29    24306.96      157.23        1.78     88.30     88.00
Speed exceedance        340.66    27203.67      657.39       10.66     62.92     58.67
Speed exceedance        360.42    28368.80       84.67        1.37     65.08     58.67
Speed exceedance        376.14    29638.45      801.13        8.93     91.09     88.00
Speed exceedance        394.38    31245.92      639.80        7.20     89.82     88.00
Speed exceedance        427.06    34084.60      317.43        3.60     88.31     88.00
Speed exceedance        487.31    37958.83        1.96        0.03     58.67     58.67
```

Figure 10. Example of STSIM automated output.

Summary measures are calculated automatically. In this example, the driver exceeded the speed limit 15 times. Each speeding mistake is listed, along with information indicating the time and distance from the beginning of the scenario.

faceLAB 5 and EyeWorks software packages

The faceLAB 5 package provides a detailed analysis of eye movements and eye closures that occur during a recording session, which may help evaluate driving performance issues (e.g., fatigue). The program generates data in both faceLAB 5 (.fll) files and .txt files. The following is a detailed list of all outcome measures provided; note that these data must be further processed using another program (e.g., MATLAB, Excel):

1. Head tracking – translation and rotation of head
2. Eye tracking
   a. left and right eye closures
   b. Percentage of Eye Closure (PERCLOS) (can adjust closure threshold and time duration window)
   c. left and right eye pupil diameters
   d. eye blinks (frequency and duration)
3. Gaze tracking
   a. left and right eye yaw, pitch, and “gaze quality” (scale of 0–3)
   b. vergence distance

The EyeWorks program provides real-time information on the direction of the driver’s point of gaze during the scenario (Figure 11). Retrospectively, the researcher can pair data generated from EyeWorks with automated STISIM program analyses to examine relationships between point of gaze/attention and driving performance. Additionally, the EyeWorks program provides detailed analyses on visual behavior and viewing patterns for regions of interest.

CONCLUSION

The driving simulator and eye-tracking systems integrated into the CAREN allow for the creation of repeatable scenarios with generated data results from the software platforms. These added abilities increase the research and rehabilitation effectiveness of the NHRC CAREN. With increased effectiveness comes the improved ability to research methods of rehabilitation for our service men and women.

Figure 10. Integration of eye tracking with driving simulator.

Example of STISIM program scenario with concurrent eye-tracking analysis. As the subject proceeds through the simulated environment, the EyeWorks program records in real time point of gaze as it shifts from one region of interest to another. The green dot is a visual representation of this gaze point.

REPORT DOCUMENTATION PAGE

1. REPORT DATE (DD MM YY)
09 07 14

2. REPORT TYPE
Technical Report

3. DATES COVERED (from – to)
Jan 2013 – July 2014

4. TITLE
Design and Integration of a Driving Simulator With Eye-Tracking Capabilities in the Computer Assisted Rehabilitation Environment (CAREN)

5a. Contract Number:
5b. Grant Number:
5c. Program Element Number:
5d. Project Number:
5e. Task Number:
5f. Work Unit Number: 61030

6. AUTHORS
Harvey Edwards, B.S, and Rachel Markwald, Ph.D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Commanding Officer
Naval Health Research Center
140 Sylvester Rd
San Diego, CA 92106-3521

8. PERFORMING ORGANIZATION REPORT NUMBER
14-9I.

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)
Commanding Officer
Naval Medical Research Center
503 Robert Grant Ave
Silver Spring, MD 20910-7500

Chief, Bureau of Medicine and Surgery
(MED 00), Navy Dept
2300 E Street NW
Washington, DC 20372-5300

10. SPONSOR/MONITOR'S ACRONYM(S)
BUMED/NMRC

11. SPONSOR/MONITOR'S REPORT NUMBER(s)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

While the D-Flow software has many applications intended for walking, running, and balance, it does not include any premade driving simulation scenarios. The driving simulator NHRC required would have a variety of easily modified road courses, the ability to collect data for research purposes, simulate realistic automobile movements using the motion base platform, and the ability to integrate an eye-tracking system. While the D-Flow software is capable of controlling the system and creating driving scenarios, it does not contain a variety of easily modified road courses, has no module to simulate realistic automobile movements during driving, and does not allow for eye-tracking capabilities. The driving simulator and eye-tracking systems integrated into the CAREN allow for the creation of repeatable scenarios with generated data results from the software platforms. These added abilities increase the research and rehabilitation effectiveness of the NHRC CAREN.

15. SUBJECT TERMS
CAREN, Naval Health Research Center, NHRC, Motek Medical, driving simulator, eye tracking

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	18a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Commanding Officer
UNCL	UNCL	UNCL	UNCL	14	18b. TELEPHONE NUMBER (INCLUDING AREA CODE) COMM/DSN: (619) 553-8429

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18