Driver360: A Four-Dimensional Scanning System to Better Understand Drivers

SAFETY RESEARCH USING SIMULATION

UNIVERSITY TRANSPORTATION CENTER

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Abstract

The main objective of this project was to construct a four-dimensional (4D = spatial + temporal) scanning system that can be installed in a driving simulator environment. The novel 4D scanning system, named *Driver360*, comprises 32 digital single lens reflex (DSLR) cameras and captures time-synchronized high-definition (HD) videos ($\geq$ 1080p) of a subject sitting in and operating a driving simulator from different angles. In this project, a portable structure that mounts the cameras and can be attached to the existing NADS MiniSim simulator was designed, tested, and manufactured. The structure comprises three moveable stands that are attached to the front, left, and right sides of the NADS MiniSim setup. The cameras mounted on the stands are facing the driver seat from a configuration that we empirically found is suitable. An electronics-controlled triggering system of the Driver360 system was added so the cameras can be triggered all at once.

1 Introduction

1. Overview of the system

The objective of this project was to construct a four-dimensional (4D = spatial + temporal) scanning system that can be installed in NADS-MiniSim driving simulator environments. The proposed 4D scanning system, named *Driver360*, can capture time-synchronized high-definition (HD) videos (≥ 1080p) of a subject sitting in and operating a driving simulator from different angles. The system then combines the videos, detects visual features and landmarks, and integrates them to reconstruct a 3D model for each video frame. The reconstructed models in the video frames are then concatenated to construct a dynamic 3D scan of the driver over time (see Figure 1.1)

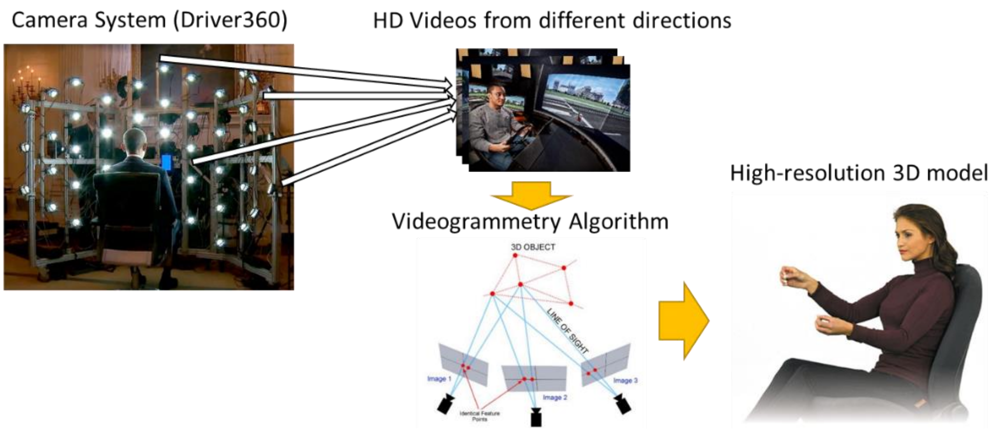

Figure 1.1 - Overview of the proposed system

The major goal of this project was to prepare an infrastructure to enable future research studies utilizing such a system. To this end, a hardware structure for seamlessly installing cameras in the driving simulator environment was designed and fabricated, and an electronic triggering system for time-synchronized control of the cameras was built. These systems were integrated and installed in the NADS MiniSim simulator in the Seamans Center at the University of Iowa.

2. Importance/Impact

The major outputs of the proposed infrastructure are two-fold: (1) a set of time-synced HD videos of a driver's behavior taken from different viewing angles and (2) a dynamic 3D surface scan of a driver. The proposed system and the data it produces will be of great value and will result in many externally funded research opportunities in various facets of driving research.

1.1.1 More accurate assessment of driver behaviors

Current driver behavior assessment methods are limited by the capacity of conventional measurement devices. Oftentimes, non-intrusive measurement of accurate body posture and facial expression is hardly achievable. The data produced by the proposed system provide significantly more comprehensive measurement of the driver state.

1.1.2 Data for training machine-learning-based computer vision algorithms

Despite much progress in the area of machine learning, especially with the new trend of deep neural networks, a lot of computer vision techniques are still not applicable to driver studies. This is mainly due to a significant lack of annotated driver videos and images, which require a lot of tedious manual labor. Data collected through the proposed system will greatly facilitate various research endeavors to this end, as the 3D model generated from Driver360 along with the associated HD images allow automatic detection and annotation of different components (e.g., body parts) through artificially generated training datasets.

1.1.3 Creation of a realistic simulation avatar

A crucial component of driving simulators is realistic avatars. For the research efforts taking place at the NADS for the development of connected simulation systems, having a realistic driver avatar will play a critical role. To this end, the proposed system has the capability to capture realistic digital human models with high-quality texture data and to produce a large and diverse library of avatars with a variety of demographics and anthropometry. The parametric modeling technique presented by Baek and Lee [1] is directly applicable to the data captured by the proposed Driver360 system and provides a parametric driver avatar modeling tool where a user, even without a computer graphics background, can easily create and model a highly realistic driver avatar by simply entering body-sizing parameters.

1.1.4 Vehicle ergonomics based on digital anthropometry

The accuracy of the proposed system is in the scale of millimeters, which allows an accurate measurement of anthropometric sizes. This could be a valuable resource for vehicle ergonomics and anthropometry research, once sufficient and diverse enough data is collected.

2 Outcomes

The proposed project has been successfully completed with all the deliverables installed in place. What follows are the details.

3. Hardware/Structure

A camera rig structure is crucial for mounting cameras and installing them seamlessly to the simulator environment. The hardware structure comprises three main structures: the central frame and two side frames (Figure 2.1). The role of the hardware structure in the final deliverable is to mount video cameras and lighting equipment, and the structure needed to fit the current MiniSim simulator setting while being easily (un)installable and portable. Therefore, three design considerations were taken into account: (1) minimal interference with MiniSim; (2) structural stability against high rotational moment; and (3) portability and ease of installation and uninstallation.

Figure 2.1 - (Left) CAD Modeling of the Center Frame; (Right) CAD Modeling of the Side Frame

First, to achieve a proper fit and to eliminate potential interference with the MiniSim simulator setup, a dimension/fit analysis has been conducted. To this end, the MiniSim simulator has been reverse engineered and modeled in Autodesk Inventor software (Figure 2.2). Based on the reverse-engineered model, dimension of the center and side frames have been adjusted and optimized to maximize the fit while minimizing the interference. The final design is presented in Figure 2.3.

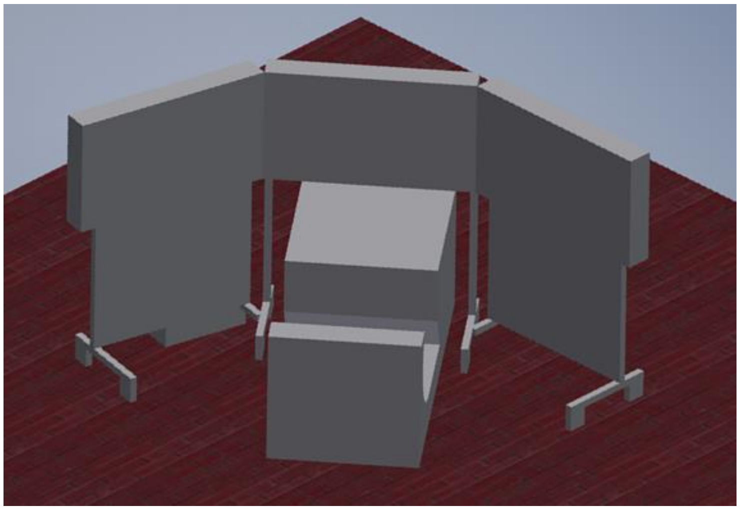

Figure 2.2 - Reverse-engineered CAD modeling of the MiniSim

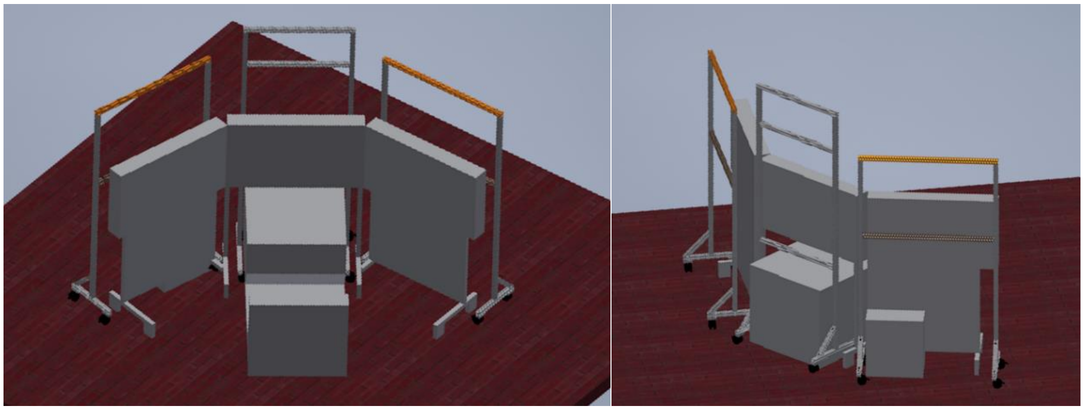

Figure 2.3 - Dimension/fit analysis of the frames: front view (left); rear view (right).

Second, the frames have to be resistant to high rotational moment created by the loading they carry. Each of the frames holds 10+ cameras, power units, and lighting units. These units face the driver's side, and it is unavoidable that all the loadings are concentrated on the front side; this causes a large moment towards the front. We therefore calculated the expected loading and the center of mass, which are the key variables for structural stability (force closure), under the loading condition. Based on the calculation, we derived the optimal foot shape of the frame so it can endure the loading.

Third, the frames by design are portable. They have caster wheels and can be dragged around easily. Electrical wirings are done independently so that there are only a few wire connections across the frames. This allows easy installation/uninstallation and transportation.

Based on the design described above, the hardware structure was fabricated on site. We employed aluminum profile extrusions from 80/20 Inc. for the main frames. 32x Velbon PH-157Q 3-way aluminum pan and tilt heads with quick release were connected to the main frame to mount the cameras (Figure 2.4). As shown in the figure, the tilt heads allow a firm hold on the cameras while allowing flexible viewing angles. The heads are compatible with standard tripods.

However, there was no standard mechanism for mounting those camera heads to the main frame aluminum extrusions. To this end, we used a T-shaped bolt so that one can simply drop the bolt head into the groove of the main frame; after a 90-degree turn, the bolt is locked inside and the head can be fixed at the location.

Figure 2.4 –Three-way pan and tilt head for mounting cameras (left); t-head bolt for connecting the heads with the main frame (middle); a head connected to an 80/20 aluminum profile extrusion (right).

4. <u>Electronic Triggering System</u>

In addition to the camera rig structure, an electronic triggering system was also built in this project. It consists of three main three parts: (1) power supply to the cameras; (2) shutter trigger; and (3) data transfer. To this end, we purchased custom-made electronic components from Esper Design Inc. (UK). The company was selected based on their incomparable experience and expertise in building multi-camera trigger systems, including the current state-of-the-art systems at the University of Southern California, Hollywood studios, video game companies, etc. What follows are descriptions of the problems that arose and the solutions we implemented in this project.

First, because 32 DSLR cameras operate in the Driver360 system, power management can be an issue. The DSLR cameras by default operate on a lithium-ion battery as a sole power source, but this can be not only inconvenient but also unstable under the 32-camera setup. We decided to use a “dummy” battery to achieve a more stable power supply (Figure 2.5). These are DC couplers that have the same shape as the original camera batteries but are wired to wall outlets so the cameras have a more stable and persistent power supply. The dummy batteries are then connected to a main power box before being connected to the wall power outlet (Figure 2.6). The role of the main power box is to convert the AC current from the wall outlet to DC current. Each power box can supply power to up to six DSLR cameras.

Figure 2.5 - DC coupler battery pack: the DC coupler (left) and a lithium-ion battery for comparison (right). The DC coupler releases the same voltage and amperage as the original lithium-ion battery but provides a more stable and persistent current.

Figure 2.6 - DC coupler connected to a main power box (left). The role of the main power box is to convert AC current into DC current. One power box can supply electric power to up to 6 DSLR cameras (right).

Second, the key to the system we built in this project was how to trigger cameras simultaneously. To this end, efficient relay and broadcasting of a shutter signal to multiple cameras with a minimal latency was the challenge. Esper Design Inc. has the leading technology amongst the very few that are available in the market. We compared their technology with the one we made in-house, and the Esper trigger box showed slightly less latency but had a significantly lower failure rate. We hence purchased six trigger boxes from Esper (Figures 2.6 and 2.7). The boxes can be connected as a daisy-chain and can broadcast signals to up to six cameras each and 36 cameras total. One of the boxes can be connected to a wired remote control (RC) unit or a computer, and the signal from the RC or the computer will be spread out to the cameras connected.

Figure 2.7 - Trigger box connected to a camera.

Figure 2.8 - Trigger box: front view and rear view.

Third, for the data transfer, we decided to use the standard USB port provided by the cameras. We purchased USB hubs to collect the USB signals and eventually deliver them to a computer.

Finally, a computer workstation was mounted to the Driver360 system, and all the data transfer cables were routed to the computer. The computer can manage photo/video data in all of the cameras at once and process them to reconstruct a dynamic 3D scene. To this end, Agisoft PhotoScan [2] software was purchased and installed on the computer.

5. Final Setup

Combining the components described above, a final setup of the Driver360 system was constructed as shown in Figure 2.9.

Figure 2.9 – Final installation of Driver360.

3 Conclusion and Future Work

6. Conclusion

In this project, a novel system for imaging a driver in a driving simulator was designed and fabricated. The system is comprised of 36 DSLR cameras that can be used to acquire time-synchronized HD photos and videos of a driver from different perspectives. To this end, a camera rig structure that is compatible with NADS MiniSim driving simulator was designed and fabricated. The structure is portable and modularized such that it can be easily transported to different locations. In addition, an electronic triggering system was also built to facilitate the time-synchronized image acquisition process.

7. Future Work

The new system can be a starting point for many innovative driving research studies. The capability of acquiring high-resolution videos enables immediate new research opportunities for measuring and analyzing driving behaviors. Data collected using the system will produce a unique, rich dataset for better understanding drivers. Furthermore, images of drivers collected via the developed system could also be used for accelerated data collection for training computer vision-based driver state detection and monitoring algorithms. An ability to acquire 3D images of drivers allows generation of artificial driver images in various scenarios. That is, the 3D reconstructed image of a driver could be rendered under different background and illumination conditions, so a lot of driving scenes could be simulated automatically, without the cost of actual data collection. In this way, numerous driving data could be collected to train computer vision algorithms to be able to detect body motions, gestures, and emotional states, resolving the bottleneck of the current machine-learning-based driver state monitoring approaches. Lastly, the system could also be used for generating a library of realistic driver avatars for simulation. Hence, these will be the future directions of our research.

References

1. Baek, S., & Lee, K. (2012). Parametric human body shape modeling framework for human-centered product design. *Computer-Aided Design*, 44(1): 56-67.
2. Agisoft Photoscan. http://www.agisoft.com/