

# ROADWAY SAFETY INSTITUTE

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## Improvement of Driving Simulator Eye Tracking Software

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Final Report



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16. Abstract (Limit: 250 words) <p>This work focuses on improving the eye tracking analysis tools used with the HumanFIRST driving simulator. Eye tracking is an important tool for simulation-based studies. It allows researchers to understand where participants are focusing their visual attention while driving.</p> <p>The eye tracking system provides a nearly continuous record of the direction in which the driver is looking with respect to real-world coordinates. However, this by itself does not give any information about the objects at which the driver is looking. To determine when a driver is fixated on a given element in the simulated world (e.g., a vehicle or sign), additional processing is necessary. Current methods to process this data are time and resource intensive, requiring a researcher to manually review the eye tracking data. This motivates an automated solution that can automatically and programmatically combine eye tracking and simulator data to determine at which object(s) (either in the real world or the simulated world) the driver is looking.</p> <p>This was accomplished by developing and implementing software capable of providing useful eye tracking data to researchers without requiring time and resource intensive human intervention and hand coding of data. The data generated by the analysis software was designed to provide a set of summary statistics and metrics that will be useful across different simulation studies. Additionally, visualization software was created to allow researchers to view key simulator and eye tracking data for context or insight or to identify and characterize anomalies in the analysis software. Overall, the software implemented will increase the efficiency with which eye tracking data can be used alongside simulator data.</p>			
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# TABLE OF CONTENTS

<b>CHAPTER 1: Introduction</b> .....	<b>1</b>
<b>CHAPTER 2: Analysis Software Required Inputs</b> .....	<b>3</b>
2.1 Simulator Data.....	3
2.1.1 Simulator Time .....	3
2.1.2 Eye Tracker Frame.....	3
2.1.3 Simulation Vehicle X, Y Position and Heading.....	3
2.1.4 Target Vehicle X and Y Position.....	4
2.1.5 Summary of Simulator Fields .....	4
2.2 Eye Tracking Data .....	5
2.2.1 Frame Number .....	5
2.2.2 Frame Rate .....	5
2.2.3 Filtered Gaze Heading .....	5
2.2.4 Fixation.....	6
2.2.5 Closest Object Intersection .....	6
2.2.6 Pupil Diameter.....	6
2.2.7 Summary of Eye Tracking Fields.....	6
2.3 Preprocessed Data.....	7
<b>CHAPTER 3: Functionality of Developed Software</b> .....	<b>9</b>
3.1 functionality of Analysis Software .....	9
3.1.1 Data Manipulation .....	9
3.1.2 Fixation Targets .....	9
3.1.3 Trial Summary Measures.....	10
3.1.4 Target Vehicle Fixation Measures .....	10
3.1.5 Other Fixation Measures.....	11

3.1.6 Pupillometry .....	11
3.1.7 Summary of Analysis Output Fields.....	12
3.2 Functionality of Visualization Software .....	13
3.2.1 Overview of Visualization Software .....	13
3.2.2 Visualization Elements .....	14
3.2.3 Sample Visualization Frames.....	15
<b>CHAPTER 4: Conclusions .....</b>	<b>17</b>
4.1 Future Work.....	17
4.2 Summary.....	17

## LIST OF FIGURES

Figure 1.1 HumanFIRST Driving Simulator .....	1
Figure 3.1 Sample View A of Visualization Software .....	15
Figure 3.2 Zoomed in View A. ....	15
Figure 3.3 Sample View B of Visualization Software. ....	16

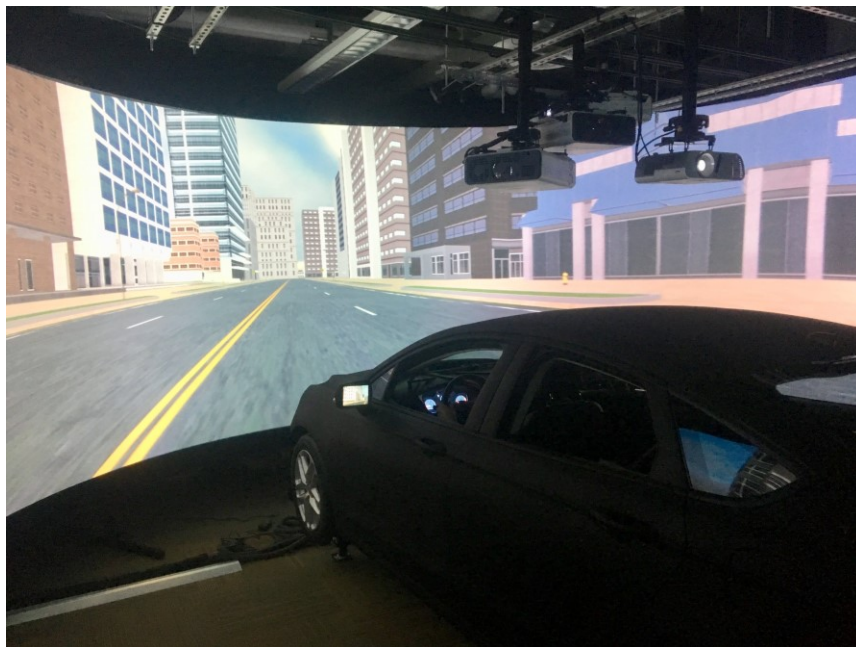
## LIST OF TABLES

Table 2.1 Summary of Simulator Fields .....	4
Table 2.2 Summary of Eye Tracking Fields.....	7
Table 2.3 Summary of Preprocessed Data .....	8
Table 3.1 Summary of Analysis Output Fields .....	12

## CHAPTER 1: INTRODUCTION

Eye tracking is a powerful tool used to determine where an individual is looking in the context of performing a given task or activity. This technique has applications across a number of industries including computer science, advertising and marketing, and psychology and neuroscience (Duchowski, 2002). The application described in this report centers on eye tracking used during driving tasks in a driving simulation. Collecting eye tracking data as a part of driving simulator studies provides insight into where drivers are placing their visual attention.

One such use of eye tracking in driving simulation is the immersive driving simulator in the HumanFIRST Laboratory at the University of Minnesota. This simulator consists of a 2016 Ford Fusion on a moving base inside a 180-degree seamless projection screen. The vehicle cab has a glass cockpit gauge cluster and a touchscreen center stack display. It was created by Realtime Technologies, a division of FAAC (Realtime Technologies, 2019). An image of the simulator environment including the screen and cab is shown in Figure 1.1.



**Figure 1.1 HumanFIRST Driving Simulator.**

The driving simulator is outfitted with a Smart Eye Pro eye tracking system (Smart Eye Pro, 2019). The system as installed on the HumanFIRST driving simulator uses four cameras mounted in the simulator cab that are pointed at the driver's head. The system uses these views along with computer vision algorithms to locate the driver's eyes and the direction in which they are looking (i.e., gaze vector information). Additional information is collected including the size of the driver's pupils, the state of their eyelids (e.g., open, closed, speed of closure, etc.), and the position and orientation of the driver's head. The system also generates a number of derivative measures such as 2D representations of the gaze vector, whether the gaze vector intersects with a known and static real-world object (e.g., the

projection screen, gauge cluster, or center stack), and groups collections of gaze vectors together, identifying them as fixations.

The current method for analyzing the eye tracking data relies on the MAPPs software by eyesDx (eyesDx, 2019). This software is primarily used to combine the gaze vector information with video of the simulation collected from a forward-facing scene camera that records the activity on the simulator screen through the windshield of the cab. This process superimposes the position of the gaze vector information on the scene camera video such that each frame of video is annotated with the approximate position within the frame where the driver is looking when the frame is captured.

The annotated scene camera video is a useful tool to assess where the driver is looking throughout the course of a simulated drive. Furthermore, researchers can use these videos to manually determine what object in the simulated world the driver is looking at as well as when and for how long. However, this process is time consuming, requiring a researcher to view the video to manually annotate when a driver is looking at a particular object in the simulated world. This motivates a solution that does not require the resource intensive operation of hand coding the eye tracking data.

The goal of this work was to implement a software tool capable of providing useful eye tracking data to researchers without requiring the lengthy process of hand coding driving scenarios. This was accomplished by automatically and programmatically combining eye tracking data such as gaze vectors that exist in the real world, with information about the simulated world as provided by the simulation software. In addition to the automated processing functionality, visualization software was also developed to help facilitate hand coding for data extraction or validation if required by the study.

This report serves primarily as technical documentation for the developed software. Chapter 2 describes the input requirements for the analysis software that must be provided by the simulator and eye tracking software as well as from a preprocessing step. Chapter 3 describes how the analysis software combines the input data and what information it outputs. It also describes the functions of the visualization software. Chapter 4 summarizes the major findings of the work and presents possibilities for future work.



## CHAPTER 2: ANALYSIS SOFTWARE REQUIRED INPUTS

The analysis software depends on three main sources of information in order to process the data from a given study and output summary statistics. The sources are the simulator's state data, the eye tracking system logs, and a list of independent events or trials and some associated metadata created by the research team. This section describes these sources and their associated input data.

### 2.1 SIMULATOR DATA

In order to be able to draw the simulated world, the simulator must keep track of its own state which includes data such as the position, orientation, and speed of the simulator vehicle, the driver's inputs to the vehicle (e.g. steering wheel angle, brake, accelerator, turn signals, etc.), the geometry of the simulated world, the dynamics of other simulated vehicles, in addition to other state information. This data is outputted by the simulator into a data file that is saved at the end of each drive (i.e. each time a scenario ends).

The simulation engine runs at 20 Hz meaning the world's dynamics are updated every  $1/20^{\text{th}}$  of a second however, it logs data at 60 Hz. That means at every  $1/60^{\text{th}}$  of a second time step, the simulator's state is written to file. The result is a table with the described field names as column headers and each time step as a single row. The following sections describe the data outputted by the simulation engine that is used as an input to the analysis software.

#### 2.1.1 Simulator Time

---

The simulator maintains a running timer that allows it to log the time elapsed (in seconds) since the current simulator scenario or drive was started. This value is used to represent the time elapsed in a given trial and to calculate the duration of simulator events.

#### 2.1.2 Eye Tracker Frame

---

The eye tracking software provides a unitless and arbitrary, incrementing serial number for each time step or frame. This frame number is sent over the network from the eye tracking software to the simulation engine in order to provide a link between the two data sources. This is the sole source of synchronization between the two sources.

#### 2.1.3 Simulation Vehicle X, Y Position and Heading

---

The simulation engine reports the position of the simulator vehicle in 2 dimensions (i.e. on the ground plane) with respect to an arbitrary coordinate system origin. The x position is the distance along the x-axis or "easting" in meters and the y position is the distance along the y-axis or "northing" in meters. The simulator vehicle heading is reported with respect to the same coordinate system origin such that its heading is the direction the front of the vehicle is facing measured in degrees clockwise from the y-axis or "northing". This is necessary to record because the eye tracking system reports the gaze vector

information relative to a coordinate system fixed to the car so information is needed about the car's orientation within the simulated world in order to calculate intersections.

#### 2.1.4 Target Vehicle X and Y Position

---

The target vehicle is whatever non-simulator vehicle is of interest in a given trial. It is the vehicle against which gaze vector intersections and statistics are calculated. In order to capture this information, the position of the target vehicle is logged similarly to that of the simulator vehicle. That is to say its x and y position in meters relative to the coordinate system origin is recorded. It is noted that the target vehicle's heading is not recorded.

#### 2.1.5 Summary of Simulator Fields

---

Table 2.1 summarizes the data captured from the simulation engine for use as an input to the analysis software. The table is organized such that each field corresponds to a column of the log file created by the simulator.

**Table 2.1 Summary of Simulator Fields**

<b>Field</b>	<b>Description</b>
<b>Simulator Time</b>	The elapsed time in seconds of the current drive according to the simulation engine.
<b>Eye Tracker Frame</b>	The eye tracking frame that was current at the time the simulation engine wrote a particular row to the log file.
<b>Target Vehicle X Position</b>	The x position in meters of the target vehicle.
<b>Target Vehicle Y Position</b>	The y position in meters of the target vehicle
<b>Sim Vehicle Heading</b>	The heading (clockwise from the y-axis) in degrees.
<b>Sim Vehicle X Position</b>	The x position in meters of the simulation vehicle.
<b>Sim Vehicle Y Position</b>	The y position in meters of the simulation vehicle.

## 2.2 EYE TRACKING DATA

The eye tracking system uses 4 cameras and computer vision algorithms to measure the position and orientation of the driver's head and eyes. Additionally, data about the driver's eyes such as pupil size and eye lid closure are captured as well. This data is also processed into derivative forms including filtered measures of the gaze vector as well as segmenting the gaze data into fixations and saccades.

Here the term fixation is used to describe a collection of consecutive gaze vectors aggregated by visual angle and time. Saccades are the eye movement that connects consecutive fixations. A more in-depth description of these and related eye tracking terminology may be found in the literature such as Holmqvist et. al. (2011). It is noted that the fixation and saccade segmentation is performed by the eye tracking system and analyzing the exact metrics used for making these determinations is outside the scope of this project. These criteria are configurable within the eye tracking software as described in its documentation.

The eye tracking system operates at 60 Hz meaning at each frame (i.e. time step) the current set of data is written to a file similar to the simulation log file. The following sections describe the data outputted by the eye tracking system that is used as an input to the analysis software. Where applicable the fields are also identified by the column header used in the eye tracking system output file.

### 2.2.1 Frame Number

---

Each frame (i.e. time step) in the eye tracking system is given an integer serial number that increments by one at each time step. This is a unitless index used to identify a particular frame. The eye tracking software also sends this value to the simulation engine so that it may also log this number along side its current frame or simulation step. This number is used to link these two sources of data. This field is identified in the eye tracking software output as "FrameNumber".

### 2.2.2 Frame Rate

---

The current frame rate of the system in Hz. With the system's current configuration, the nominal frame rate is 60. This value is used to determine a frame duration used to time the duration of fixations. This field is identified in the eye tracking software output as "FrameRate".

### 2.2.3 Filtered Gaze Heading

---

The filtered gaze heading is a derivative measure calculated from the gaze vector as projected onto the 2D ground plane. It is reported in radians clockwise such that a value of 0 radians corresponds to looking straight backwards and a value of pi corresponds to looking straight forward. Here, the filtered version of this value is used which means a small amount of smoothing is performed by the eye tracking software. This results in a value with less jitter. This field is identified in the eye tracking software output as "FilteredGazeHeading".

#### 2.2.4 Fixation

---

This field is an integer serial number given to each fixation such that each subsequent, consecutive fixation is incremented by one. The field is zero if in a given frame, there is no fixation but rather a saccade. This field is used to aggregate individual gaze headings into fixations. This field is identified in the eye tracking software output as “Fixation”.

#### 2.2.5 Closest Object Intersection

---

The eye tracking software maintains a user created model of the simulator’s real-world geometry. Here, static regions of interest are identified in the eye tracking software corresponding to real-world objects such as the gauge cluster, center stack, the windscreen, etc. Using the positions of these objects, it calculates and reports the closest object to the gaze vector for each frame. This field reports the name of the object as previously defined in the real-world model. This field is identified in the eye tracking software output as “ClosestWorldIntersection.objectName”.

#### 2.2.6 Pupil Diameter

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This field is the consensus diameter in meters of the pupils of both eyes. This field is identified in the eye tracking software output as “PupilDiameter”.

#### 2.2.7 Summary of Eye Tracking Fields

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Table 2.2 summarizes the data captured from the eye tracking software for use as an input to the analysis software. The table is organized such that each field corresponds to a column of the log file created by the eye tracking software.

**Table 2.2 Summary of Eye Tracking Fields**

<b>Field</b>	<b>Description</b>
<b>Frame Number</b>	An incrementing, integer serial number labeling an individual eye tracking system frame.
<b>Frame Rate</b>	Current frame rate of the eye tracking system in Hz.
<b>Filtered Gaze Heading</b>	A time filtered projection of the gaze vector onto the ground plane reported in radians clockwise from the vehicle reverse direction.
<b>Fixation</b>	An incrementing, integer serial number labeling an individual fixation. This value is zero if the frame represents a saccade.
<b>Closest Object Intersection</b>	The closest, static object in the real-world to the driver's gaze vector.
<b>Pupil Diameter</b>	The consensus diameter in meters of the driver's pupils.

### 2.3 PREPROCESSED DATA

The required preprocessed data is a file containing meta-data required by the analysis software. It gives structure to the raw data outputs provided by the simulation engine and the eye tracking software. The file is structured such that each row corresponds to a single trial of the experiment. Here, an individual trial is an event which is an independent combination of treatment levels. It is noted that an individual participant will likely experience multiple trials.

The most critical pieces of information stored in this file are the filenames of the eye tracking log file and the simulation log file and the frame numbers that bound the trial. To generate the bounding frame numbers (i.e. the start frame number and the end frame number), preprocessing must be performed to identify the extents of the trials. For example, this may be accomplished based on flags set within the simulator data based on events or driver actions, time-based criteria, or criteria based on the position of the simulator vehicle or target vehicles. It was determined that this step would be separate from the analysis software in order to keep it as general as possible leaving the study dependent task of identifying the extent of an individual trial to study researchers.

The file may also contain information about treatment levels for each trial. Although not considered by the analysis software, it allows the researcher analyzing the experimental results to query the analysis software's output in a logical way.

**Table 2.3 Summary of Preprocessed Data**

<b>Field</b>	<b>Description</b>
<b>Eye Tracking Log File</b>	The name of the log file created by the eye tracking software.
<b>Simulation Log File</b>	The name of the log file created by the simulation engine.
<b>Participant ID</b>	The participant ID for this trial.
<b>[Treatment Level Data]</b>	A number of columns each corresponding to a treatment.
<b>Start Frame</b>	The eye tracking system frame number corresponding to the start of a trial.
<b>End Frame</b>	The eye tracking system frame number corresponding to the end of a trial.

## CHAPTER 3: FUNCTIONALITY OF DEVELOPED SOFTWARE

### 3.1 FUNCTIONALITY OF ANALYSIS SOFTWARE

The primary goal of the analysis software is to provide a collection of summary statistics on a per-trial basis. This is accomplished by first considering all the data from a trial on a per-fixation basis. This largely consists of determining the object at which the driver is looking for a given fixation. Then the fixations for a given trial are combined to calculate per-trial data which is then outputted to file. This section describes the intermediate steps required to generate this information as well as the final output statistics.

#### 3.1.1 Data Manipulation

---

The first step in this process is preparing the data for the analysis algorithms. The software analyzes the data a single trial at a time based on the information stored in the preprocessing and metadata file. This information is used to access the eye tracking log file and the simulation engine log file. The files are then loaded and filtered as they only need to store the columns identified in Chapter 2. The data from each file is then merged together based on the frame number. This creates a new table where a single row corresponds to a single frame but contains the data from both the simulator and the eye tracker.

Using the start and end frames from the preprocessing file, the data is filtered again to only include data occurring between the start and stop frames. This yields only the frames corresponding to the trial under consideration.

#### 3.1.2 Fixation Targets

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The core function of the analysis software is determining at what object, either in the real world or the simulated world, the driver is looking. This is done on a per-fixation basis. That is to say once the data manipulation step is complete and the table consists only of data corresponding to a single trial, the software considers a single fixation at a time. For each fixation, the gaze heading is averaged over the duration of the fixation. This mean gaze heading (relative to the simulated vehicle) is then combined with the simulated vehicle's mean heading over the fixation (relative to the simulated world's coordinate frame) which yields the heading of the fixation relative to the simulated world. This fixation heading is then compared to the heading from the simulated vehicle to the target vehicle as calculated by their relative positions.

The algorithm determines that the driver is looking at the target vehicle if the difference between the fixation heading and the heading to the target vehicle is less than 10 degrees. This threshold was chosen empirically in order to account for accuracy errors in the eye tracking system. However, if the eye tracker reported that the driver was already looking at the gauge cluster or the center stack, this would override the previous calculation. This is because if the driver was looking inside the vehicle, their gaze heading may still point towards the target. This yields the fixation target which corresponds to the target viewed during a given fixation. This set of calculations is then repeated for each fixation in the trial.

### 3.1.3 Trial Summary Measures

---

#### 3.1.3.1 Total Trial Time

The total trial time is a measure of the duration of the trial in seconds. It is calculated by finding the difference between the simulator time at the beginning of the trial and at the end of the trial.

#### 3.1.3.2 Total Number of Fixations

The total number of fixations is the count of unique fixations as identified by the eye tracking software over the duration of the trail.

#### 3.1.3.3 Fixations Per Second

The number of fixations per second is a derivative measure calculated by dividing the total number of fixations by the total trial time.

#### 3.1.3.4 Total Fixation Time

The total fixation time is a measure of the total time spent in a fixation in seconds, as opposed to time spent in a saccade. This is calculated by summing the fixation durations for a given trial.

### 3.1.4 Target Vehicle Fixation Measures

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#### 3.1.4.1 Fixations on Target Vehicle

The number of fixations on the target vehicle is a count of the unique fixations within a trial whose fixation target was the target vehicle as determined by the algorithm described above. If the participant never fixates on the target vehicle, this value is reported as NaN (i.e. not a number).

#### 3.1.4.2 Time on Target Vehicle

The time on target is a measure of the total amount of time in seconds spend fixated on the target vehicle. This is calculated by summing the duration of all fixations within a trial whose target was the target vehicle. If the participant never fixates on the target vehicle, this value is reported as zero.

#### 3.1.4.3 Percent Time on Target Vehicle

The percent time on target vehicle is a derivative measure calculated by dividing the time on target vehicle by the total trial time. If the participant never fixates on the target vehicle, this value is reported as zero.



#### 3.1.4.4 Time to First Target Vehicle Fixation

The time to first target vehicle fixation is the time elapsed in seconds in a trial before the first fixation on the target vehicle occurs. If the participant never fixates on the target vehicle, this value is reported as NaN.

### 3.1.5 Other Fixation Measures

---

#### 3.1.5.1 Percent Time on Road

The percent time on road is a measure of the percent of time spent fixated on an object outside the vehicle (e.g. road, target vehicle, other external objects, etc.) as opposed to on an object within the vehicle (i.e. the center stack or gauge cluster). It is calculated by summing the total time spent in a fixation, excluding the time spent fixated on the center stack or gauge cluster, divided by the total trial time.

#### 3.1.5.2 Percent Time Centered on Road

The percent time centered on road is a measure of the percent of time spent looking outside the vehicle within 10 degrees of center. This is calculated by summing the total time spent in a fixation outside the vehicle (i.e. not on the gauge cluster or center stack) where the fixation heading was within 10 degrees of center (i.e. straight ahead). This sum is then divided by the total trial time.

### 3.1.6 Pupillometry

---

The Smart Eye Pro eye tracking system, in addition to measuring the driver's head and eye position and orientation, is also capable of measuring the diameter of the driver's pupil. Pupil diameters are considered in aggregate in two mutually exclusive conditions, the initial portion of a trial before the driver fixates on the target vehicle, and the portion of the trial when the driver is fixated on the target. This provides a difference in pupil diameters between baseline conditions and when fixated on the target vehicle.

#### 3.1.6.1 Initial Trial Pupil Diameter

The initial trial period as defined for, the purposes of aggregating pupil diameter statistics, is the period starting at the beginning of the trial until the driver first fixates on the target vehicle or until 5 seconds elapse, whichever occurs first. The mean and standard deviation is then calculated over the pupil diameter observed at each frame within the initial trial period. These values are reported in meters. If the driver begins the trial fixated on the target vehicle, this value is reported as NaN.

#### 3.1.6.2 Target Fixation Pupil Diameter

The mean and standard deviation (in meters) is also calculated for the pupil diameters observed when the driver is fixated on the target vehicle. This is done regardless of the number of times or the amount

of time spent fixated on the target vehicle. If the driver never fixates on the target vehicle, this value is reported as NaN.

### 3.1.6.3 Pupil Diameter Difference

The pupil diameter difference is the change in mean pupil diameter in meters calculated by subtracting the target fixation pupil diameter mean from the initial trial pupil diameter mean. If either the initial trial pupil diameter or the target fixation pupil diameter is NaN, then this value will be reported at NaN as well.

### 3.1.7 Summary of Analysis Output Fields

---

Table 3.1 summarizes the data outputted from the analysis software. The data generated by the analysis software is calculated per-trial and is reported in the same table as the preprocessed input data. This table is organized such that each field corresponds to a column appended to the preprocessed input data.

**Table 3.1 Summary of Analysis Output Fields**

<b>Field</b>	<b>Description</b>
<b>Total Trial Time</b>	The duration in seconds of the trial.
<b>Total Number of Fixations</b>	The count of unique fixations on any object during the trial.
<b>Fixations Per Second</b>	The number of fixations divided by the total trial time.
<b>Total Fixation Time</b>	The total amount of time in seconds spent in a fixation, as opposed to a saccade, during the trial.
<b>Fixations on Target Vehicle</b>	The count of unique fixations on the target vehicle during the trial.
<b>Time on Target Vehicle</b>	The total amount of time in seconds spent fixated on the target vehicle during the trial.
<b>Percent Time on Target Vehicle</b>	The time spent fixated on the target vehicle as a percent of the total trial time.

<b>Time to First Target Vehicle Fixation</b>	The elapsed time in seconds before the driver first fixates on the target vehicle.
<b>Percent Time on Road</b>	The time spent fixated outside the cab of the vehicle as a percent of the total trial time.
<b>Percent Time Centered on Road</b>	The time spent fixated outside the cab, within 10 degrees of center (i.e. straight ahead) as a percent of the total trial time.
<b>Initial Trial Pupil Diameter Mean</b>	The mean of the pupil diameter in meters over the first 5 seconds of the trial or until the driver first views the target vehicle, whichever occurs first.
<b>Initial Trial Pupil Diameter Standard Deviation</b>	The standard deviation of the pupil diameter in meters over the first 5 seconds of the trial or until the driver first views the target vehicle, whichever occurs first.
<b>Target Fixation Pupil Diameter Mean</b>	The mean of the pupil diameter in meters over the entire time spent fixated on the target vehicle.
<b>Target Fixation Pupil Diameter Standard Deviation</b>	The standard deviation of the pupil diameter in meters over the entire time spent fixated on the target vehicle.
<b>Pupil Diameter Difference</b>	The difference in meters between the target fixation pupil diameter mean and the initial trial pupil diameter mean.

## 3.2 FUNCTIONALITY OF VISUALIZATION SOFTWARE

### 3.2.1 Overview of Visualization Software

The primary goal of this work was to create an automated method for analyzing the data produced by the simulation engine and the eye tracking software. To support such an analysis, a visualization tool was created to help better understand driver eye behavior throughout a trial. A GUI (graphical user interface) was created to display and control the visualization.

There are numerous ways to visualize eye tracking data and these methods have strengths and weaknesses depending on the particular application (Blascheck et. al., 2014). Because this application was in support of an automated analysis tool, the visualization software was limited to core functionality

required to view the relative positions of the simulated vehicle, target vehicle, and the driver's gazes and fixations.

The GUI is designed to visualize a single trial at a time. Upon launch, the GUI must be given a data file that contains all the required visualization data. This is a table where each row is a single frame of the combined simulator and eye tracking data as well as intermediate and output data from the analysis algorithms. Although this data could be calculated in real time by the GUI software, it is instead loaded from this GUI-specific data file in order to avoid having to load in, merge, filter, and analyze the data which can be slow depending on the size of the raw data files.

### 3.2.2 Visualization Elements

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The GUI software shows the visualization as well as a slider to scrub through the data for the given trial. There are also arrow buttons to step forward and backward through the data a single frame at a time. The visualization displays four key components: the simulation vehicle, the target vehicle, the gaze heading, and the fixation heading.

The simulation vehicle is drawn as a solid blue rectangle with a length and width of 4.8 meters by 1.9 meters, the approximate dimensions of a Ford Fusion (the vehicle upon which the simulation vehicle is modeled). It is drawn such that it is at the left side of the visualization window and is facing right. The extent of the window is determined for each frame of data such that the simulation vehicle is always visible as well as 25 meters to the vehicle's right and left (i.e. up and down in the visualization window). The longitudinal extent of the window is selected such that it incorporates the entire extent of the simulated vehicle's future travel path over the trial. For example, when viewing the first frame, the entire travel path is visible but as the user progresses through the frames, the window zooms in only showing its remaining travel path.

The target vehicle is represented by a green circle with a radius of 1 meter. This is because target vehicle heading is not reported by the simulation engine so this shape is used as an approximation. It is noted that the 2 meter diameter does not necessarily correspond to the 10 degree buffer used when determining whether the driver is fixated on the target vehicle. The target vehicle is not always visible in the visualization window rather; it is only visible when it is located within the extent as described above.

The visualization also displays the filtered gaze heading which corresponds to the driver's gaze vector as projected into the top-down 2D plane. This is drawn as a grey line segment extending from the vehicle in the direction of the gaze vector. Additionally, the visualization also displays the fixation heading which corresponds to the mean filtered gaze heading averaged over the duration of a given fixation. This is also drawn as a line segment extending from the vehicle in the direction of the fixation heading. This line is colored depending on the object on which the driver is fixated. When the driver is fixated on an object in the car (i.e. center stack or gauge cluster), the segment is colored blue (matching the color of the simulation vehicle rectangle). When the driver is fixated on the target vehicle, the line is colored green (the color of the target vehicle circle). Lastly, all other fixations are drawn in black.

### 3.2.3 Sample Visualization Frames

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Figure 3.1 and Figure 3.2 show a sample view of the visualization software. Here, the blue rectangle representing the simulated vehicle is shown. The filtered gaze heading is drawn in grey and the fixation heading is drawn in black.

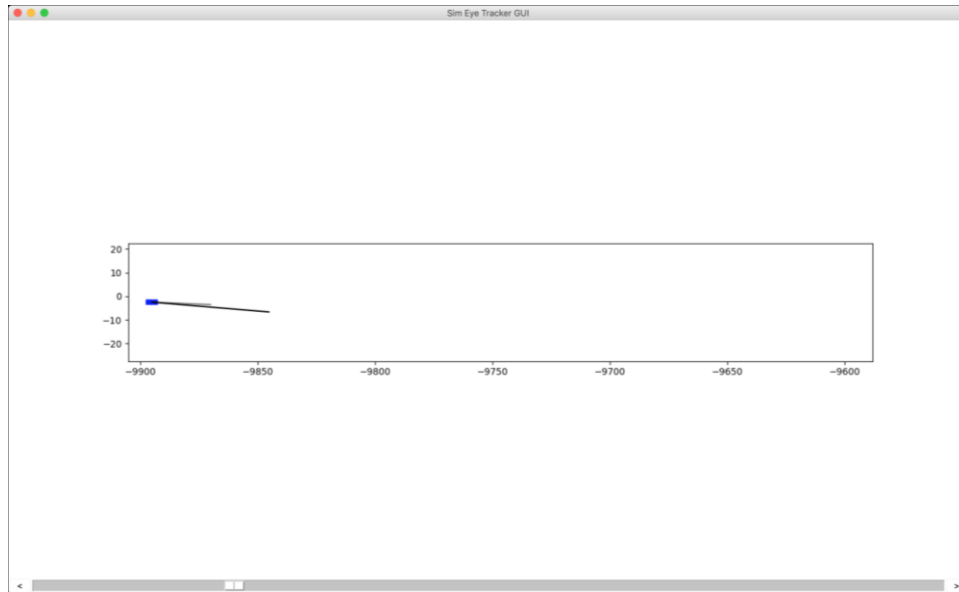


Figure 3.1 Sample View A of Visualization Software.

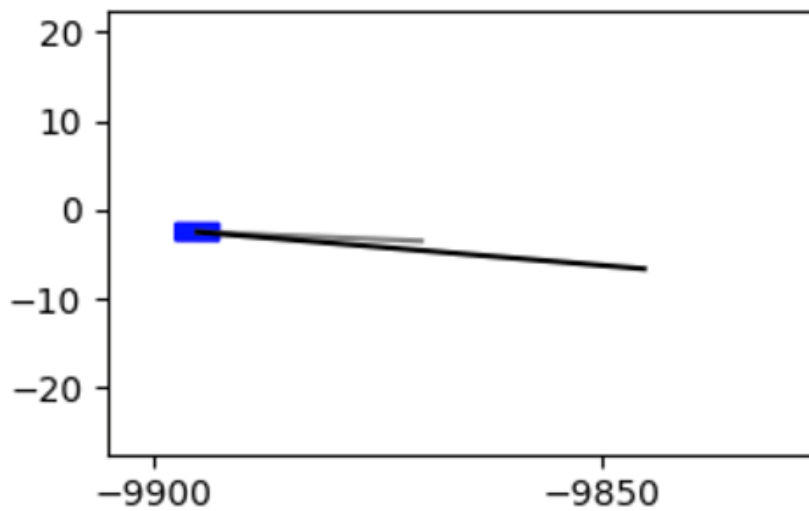


Figure 3.2 Zoomed in View A.

Figure 3.3 shows another sample view of the visualization software. Again the simulation vehicle, filtered gaze heading, and fixation heading are visible. In this frame, the target vehicle is also visible, represented by the green circle. Here the fixation heading is colored green to signify that the fixation is on the target vehicle.

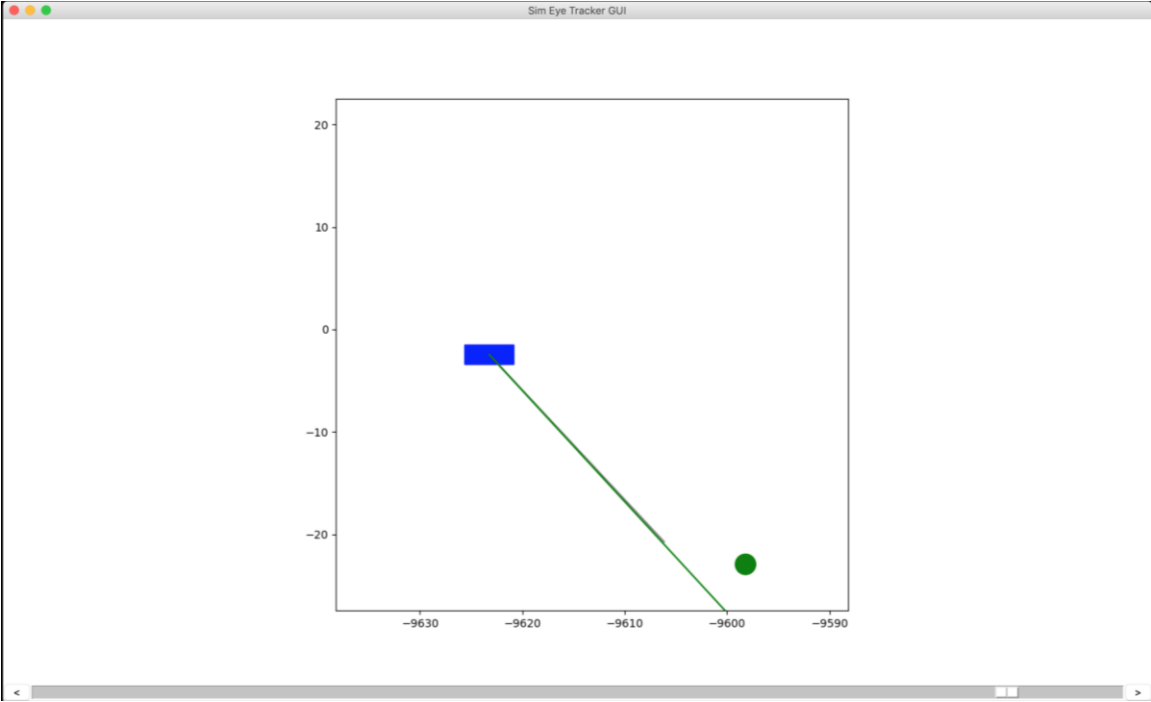


Figure 3.3 Sample View B of Visualization Software.

## CHAPTER 4: CONCLUSIONS

### 4.1 FUTURE WORK

This work focused on developing automated methods for analyzing the eye tracking data, and as such, the visualization software was limited to the core functionality necessary to view simulator and eye tracking data to sample select trials for context or insight or to identify and characterize anomalies in the analysis software. It may be beneficial for future work to enhance the capabilities of the visualization software. This could include additional views of the scenario such as a side view to provide information about the pitch (up/down angle) of the gaze vector. Providing additional scenario geometry and elements may be useful for providing context. These elements may include the road, lane lines, signs, or a more detailed model of the target vehicle.

The analysis software is currently designed to identify fixations on a single target vehicle. Thus, although the phrase target vehicle is used, the target could be a static object such as a sign. However, additional functionality could be added that would allow for multiple targets of interest. This would be useful in scenarios where the driver is interacting with multiple vehicles, signs, or other simulation elements.

### 4.2 SUMMARY

The goal of this work was to improve the eye tracking tools used with the HumanFIRST driving simulator. Software was designed and implemented that is capable of providing useful eye tracking data to researchers without requiring time and resource-intensive human intervention and hand coding of data. The data generated by the analysis software was designed to provide a set of summary statistics and metrics that will be useful across a number of different simulation studies. Overall, the software implemented will increase the efficiency with which eye tracking data can be used alongside simulator data.

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