Chalmers University of Technology

TME 180 - Automotive Engineering Project

Final Report

Drivers' Visual Strategies when a Steering Assistance System Fails

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Abstract

Since the rapid flourish of automobiles in the 21st century, the need for easier and faster transportation by means of automobiles has risen. In recent years, driving has ranged from being a daily routine task to a sport. This has given rise to adapt to the needs for a more efficient automobile. A driving task can simply be defined as all the activities that the driver engages in, so as to accomplish the aim of mobility. In the past, the driver had to do all of the tasks that contributed to the driving task. With the invent and advancement of technology, systems have been developed which assist the driver in accomplishing this driving task. One example of such an assistance system is a steering assistance system. A steering assistance system assists the driver to keep the vehicle in lane i.e., to maintain the lateral control of the vehicle. Nevertheless, such a steering assistance system is subject to failure and hence there is need to understand how humans react when such a failure occurs. Specifically, when a steering assistance system fails, the most common effect is the vehicle departing from the lane, if the driver does not regain control of the vehicle. In this experiment, such a steering automation failure is simulated using a joystick control and an eye tracker is used to study the glance behaviour of the drivers when such a failure occurs. Another objective of this experiment was to understand if there existed any relation between the driver's visual strategies and their ability to regain control of the vehicle. Data was collected from participants who drove an instrumented car on the AstaZero proving ground in Borås, Sweden. Data from various sensors in the car was collected and eye fixation points from the eye tracker has been used to analyze how driver respond during such steering assistance system failures. An interesting observation was that the drivers' interaction with the steering was directly related to their level of trust on the system. Another observation from the driver's glance behaviour shows that the driver focused lesser on the road when the vehicle was in the steering assistance mode rather than in manual driving mode, but after the failure the driver's gaze was more focused on the road ahead.

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1 Introduction

Automating the driving task has been an engineering challenge since the 1920s' [1].The major product innovations in the automotive industry are related to automation of driving [2]. Advancements supporting exceptionally automated vehicles are expected to fundamentally diminish the recurrence of crashes and fatalities, increase mobility, and lessen fuel emissions. Evaluations of when the first fully automated vehicles will be out and about differ from 10 to 20 years [3], albeit some anticipate they'll be seen much sooner depending on the achievements of demonstration projects [4]. Most vehicles, however are, as of now equipped with systems that are automated to some degree. There are systems, for example, Adaptive Cruise Control (ACC), Electronic Stability Control (ESC), power brake assist and power steering assist that help fundamental components of the driving task. In spite of the fact that drivers have been depending on these assistance systems for quite a while, they are frequently unaware of the functions they perform.

The degree of automation for on-road vehicles are characterized by the Society of Automotive Engineers (SAE, 2018) into various levels, from level 0 up to full driving automation [12]. At the highest levels (4-5), the automated driving system (ADS) should perform the entire dynamic driving task (DDT), with no desire that a user will react to a demand to intervene. However, at lower levels, the driver is either expected to be responsive to ADS' request to intervene (level 3) or to oversee the driving automation system (level 2). The primary human factors issue with SAE Level 3 is that the driver is the fallback solution. The driver is expected to take control of the vehicle in critical situations that the vehicle can't resolve. In this way, a distracted driver might be called back to the driver task all of a sudden to resolve a complex situation. The desire that a driver may take control in a critical situation in the wake of having been unaware of what's going on for quite a while is troublesome for the human factors. Humans are bad at monitoring situations: they get exhausted and lose focus. It additionally requires some investment for the human to change their "psychological state" from being a passenger to be responsible for driving the vehicle [12]. Existing exploration has warned about conceivable human factors issues related with the supervisory role of the driver, including among others skill degradation, carelessness, and negative behavioral adjustments. Given that automated vehicles may fail, a relevant question is a manner by which drivers will respond in those circumstances [12]. Numerous past studies have explored driver reaction to takeover demands from the automated vehicle and to a lesser degree also driver reactions to silent failures, where the automation fails without cautioning the driver.

Steering assistance systems help to keep the vehicle on the lane. Lane keeping assist system (LKAS) comprises products, for example, an electric power steering (EPS), a camera, and an electronic control unit (ECU) for ADAS. A lane keeping assist system causes drivers to maintain a strategic distance from unintentionally moving out of a lane. A contrast is made between systems steering assistance ("Lane departure warning") [19] and systems with steering assistance ("Active lane keeping assist") [18]. The former works such that, if there is a risk of a vehicle unintentionally moving out of a lane, the lane departure warning alerts the user in the form of a visual, acoustic and/or haptic signal, e.g. vibration of the steering wheel. The driver thus receives due warning of a deviation in the course and has time to take the appropriate corrective action. On vehicles with steering assistance, the active lane keeping assist can intervene and provide perceptible corrective steering action to keep the vehicle on course. The driver can override the system at any time. In the event that the driver activates the turn signal indicator to change the path/lane or turn off, the intercession which would otherwise take place on coming critically close to the corresponding road marking is suppressed.

Lane keeping assistance systems reinforce correct and easy moving at lower speeds around corners or when stopping. They additionally support sudden controlling moves to stay away from hindrances or keep up control in basic circumstances at any speed. Level of trust different drivers have on these assistance systems differ. Drivers have figured out how to anticipate that their steering systems will work faultlessly, and they do in most cases [9]. Without steering assistance, altogether more physical exertion is required to control the way of the vehicle and accuracy is lost. At the point when this happens all of a sudden, the outcomes could possibly be to great risk. Most drivers trust the technology completely and don't foresee disappointments [9]. At the point when assisted steering fails, drivers may not analyze the circumstance effectively, realize how to react properly to the surprise, or even be capable of reacting.

Nonetheless, there is just an exceptionally restricted comprehension of drivers' conduct and execution amid Level 3 of automation where Dynamic Driving Task (DDT) and Object and event detection and response (OEDR) are automated but the driver is expected to intervene as a fall back when there is a failure in the system. Here, the driver is relied upon to be "accessible for incidental control, however with an adequately comfortable transition time" [8]. The need is in this manner for drivers to stay in-the-loop and keep up their situational awareness to a satisfactory dimension which will enable them to continue control of driving when required. The purposes behind this resumption of control might be the failure of the automated system to deal with a specific driving circumstance/condition. However, examine on understanding the human variables of how drivers are associated with the "intermittent control" of the vehicle and what establishes "agreeable change time" is at present extremely constrained [8].

In recent years, there are studies that have examined drivers' collaboration with Level 3 automation, their situational familiarity with the encompassing activity and their association in other (non-driving-related) secondary tasks [8]. It shows the drivers' visual attention regarding the road center diminishes as the level of automation increments [8]. When drivers were supported by a lateral controller (lane keeping system) they, however, needed to keep up longitudinal control, their visual consideration towards the road center was higher than when driving was physically controlled yet like when both lateral and longitudinal support was given. The argument, therefore, that separated from levels of automation, the sort of automation support gave to drivers (lateral versus longitudinal) results in various dimensions of driver commitment and execution.

Road, traffic, and environmental information are expected to educate the safe driving of a vehicle. Drivers need to obtain, process and use outside data to drive the vehicle accurately. The measurable investigation has demonstrated that about 80 percent of driving data is got by visual perception [10]. The visual aid that drivers use to control their speed and heading, and how they look for gaze targets are significant. They help display and foresee the variety inclination of eye movements executed in naturalistic driving tasks so as to comprehend driving conduct.

Previous work on systems that recognize driver distraction continuously has utilized both eye tracking data and vehicle-based estimates, for example, speed and lateral position/steering. As vehicle measurements were overseen by the automated controllers in the momentum study, eye, and head tracking measures were utilized to decide drivers' distraction far from the road, amid Level 3 automation [8]. The control was either exchanged to drivers at a settled pace, or progressively; when they made a decision to turn away from the road center for too long or too often.

Eye tracking technologies that consequently track the point of an individual's gaze while that person views or interacts with a visual image have turned out to be accessible for research purposes. These technologies record the orientation of the person's eyes in a progression of samples taken at quick intervals. Based on the sampling information, researchers can quantify which location within the visual picture was focused (seen), for how long, and how often. The eye movements of the driver have been explored in various studies with different purposes.

The intention of this study is to investigate the driver eye position when steering failure occurs with sudden unforeseen shut down of steering-assisted system. The research was done to proceed with the examination of drivers' eye movements, a connection between the driver eye position and capacity to regain control of the vehicle. A group of volunteer members was requested to drive the experiment vehicle on the rural road in a closed test-track so that eye movement and vehicle driving parameters could be recorded.

2 Material and Methods

2.1 Experimental Design

The experiment was carried out on the AstaZero proving ground close to Borås. A schematic diagram of the AstaZero Proving Ground is as shown in Figure 1 [13]. This part of the report describes about the experiment performed, the equipment used in the experiment, the participants involved in the experiment, the documents used in the experiment, the procedure followed throughout the experiment and the analysis of the data collected from the experiment.

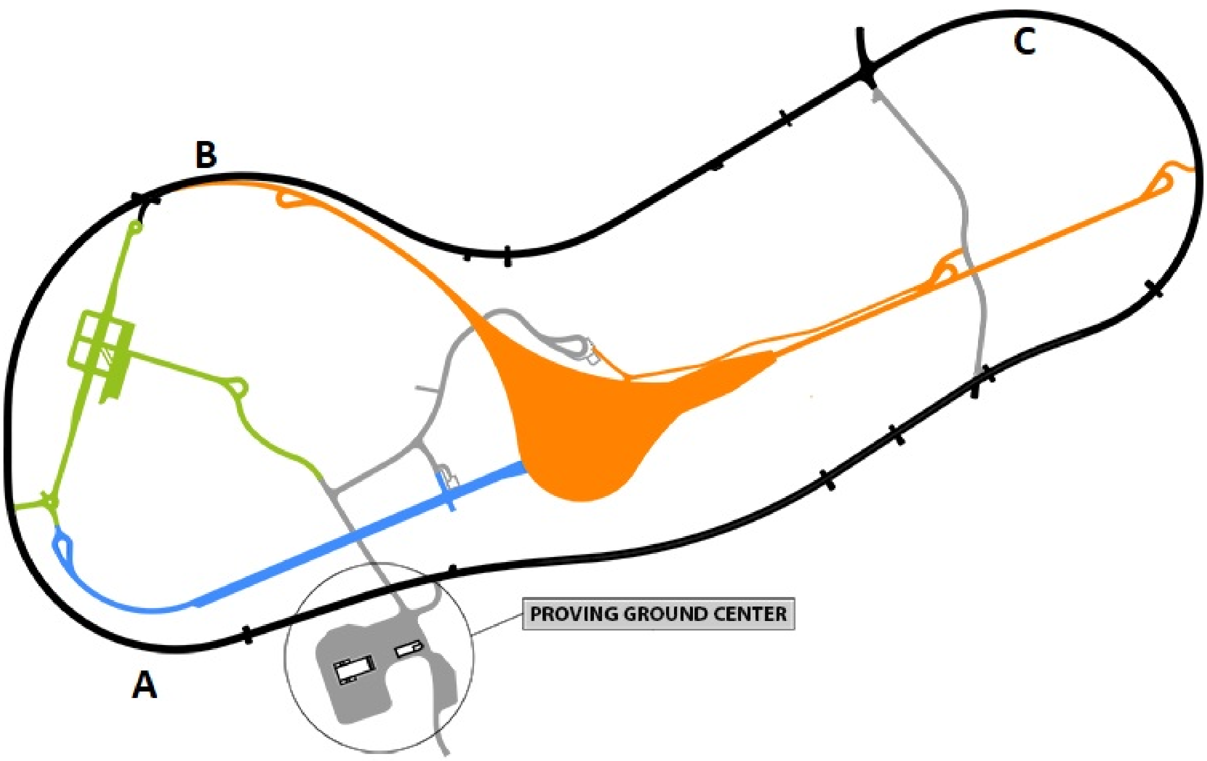


Figure 1: AstaZero track

Various vehicle parameters like vehicle speed, GPS position, heading and steering requests etc. were recorded whenever the vehicle was driven. When the vehicle was driven in steering assistance mode, along with these parameters an additionally parameter called actuation request was recorded. The actuation request corresponds to the amount of actuation given by the software. To simulate the condition of failure of the steering assistance system, the software altered the GPS position of the vehicle. This meant that the vehicle would drift out of lane at certain portions of the track.

2.1.1 Pilot session

The data collection can be classified into pilot and main session. The Pilot session was the first instance when the team got introduced to the vehicle to be used for the main experiment and was a mock-up exercise of the main day study. It provided an opportunity for the team members to get exposed to the operation of different devices installed in the equipped vehicle. Different equipment that would be part of the main data collection session were tested and calibrated for accurate results. An eye-tracker was used on a pilot participant to track the eye motions of the participant during the driving.

Prior to this experiment, a lap of the the track with the vehicle being driven in perfect lane position was recorded and the GPS positions for the entire run were extracted. The steering assistance system software used the extracted GPS co-ordinates to drive the vehicle around the track. The extracted GPS positions are the positions for which the vehicle stays perfectly within the lane. The software used specific GPS co-ordinates to start and end the lap. The procedure followed during the pilot session is described in the procedure subsection.

2.1.2 Main session

The main data collection event was on 18^{th}, 19^{th}, 23^{rd} and 24^{th} of October. Each day, 2 team members were present at the test track to guide the participants and carry out the experiment. As a token of appreciation for their participation in the experiment, the participants were awarded 2 cinema vouchers.

After the completion of the first pilot session at the AstaZero proving ground, the team received a series of knowledge transfer session at REVERE labs. During the knowledge transfer sessions, in-depth information on operating and controlling various equipment in the vehicle were received. Along with this, instructions were also provided on setting up the software to drive the vehicle in steering assistance mode. The setting up of the vehicle in the steering assistance mode is a multi-step process. The procedure to setup the software is described in the procedure subsection.

After finalizing the candidates for the experiment, the selected candidates were required to complete a mandatory AstaZero training exercise. This training gave practical information about the test track and the necessary safety information that the candidates should be aware. It also gives information to the participants about the traffic management at the test track and different communication devices used at the test track.

However, the steering assistance system software responsible to control the latitude positions of the vehicle was not providing accurate results during the pilot sessions. The vehicle would drift out of lane at random portions of the track even when the software was input with the perfect lap GPS positions. Therefore to replace the software, a joystick operated by a experimenter was used as fall-back to simulate the steering assistance mode driving of the vehicle. The experimenter would be seated in the back seat of the vehicle. The experimenter would control the latitudinal position of the vehicle while the Cruise control system (CC) would be responsible for the longitudinal control of the vehicle. Since the experimenter wasn't sure on the performance of the joystick control and the with joystick not being tuned for the experiment, the vehicle was run at 40 km/hr in steering assistance mode on the first day of the study (18^{th}). For the remaining days of the experiment (19^{th}, 23^{rd} and 24^{th}), the test was carried out at 60 km/hr. The procedure followed during main session is described in the procedure subsection.

2.2 Equipment

One of the most important tool used for this project is the car(AKA Snowfox) from REVERE labs [5]. The car is a production model Volvo XC90 equipped with various sensors and controllers. The vehicle can be driven in both manual mode and steering assistance mode. When the vehicle would be driven in steering assistance mode, steering assistance system would control the latitude position of the car while the Cruise control system (CC) would be responsible for the longitudinal control of the vehicle.

Figure 2: SnowFox

The instrumented car 'SnowFox' was used to extract data from the various sensors as well as the vehicle data such as steering wheel angle, acceleration, speed, etc., in order to enable easy analysis of collected data and enhance research. The steering assistance system in the vehicle is a software program developed by the REVERE labs. The software platform used is called OpenDLV and it is discussed below (sub section2.2.6). Shown is the vehicle (figure 2) and the vehicle architecture (figure 3). It can be seen from the architecture that the CAN data is accessed by connecting a computer to the vehicles CAN gateway.

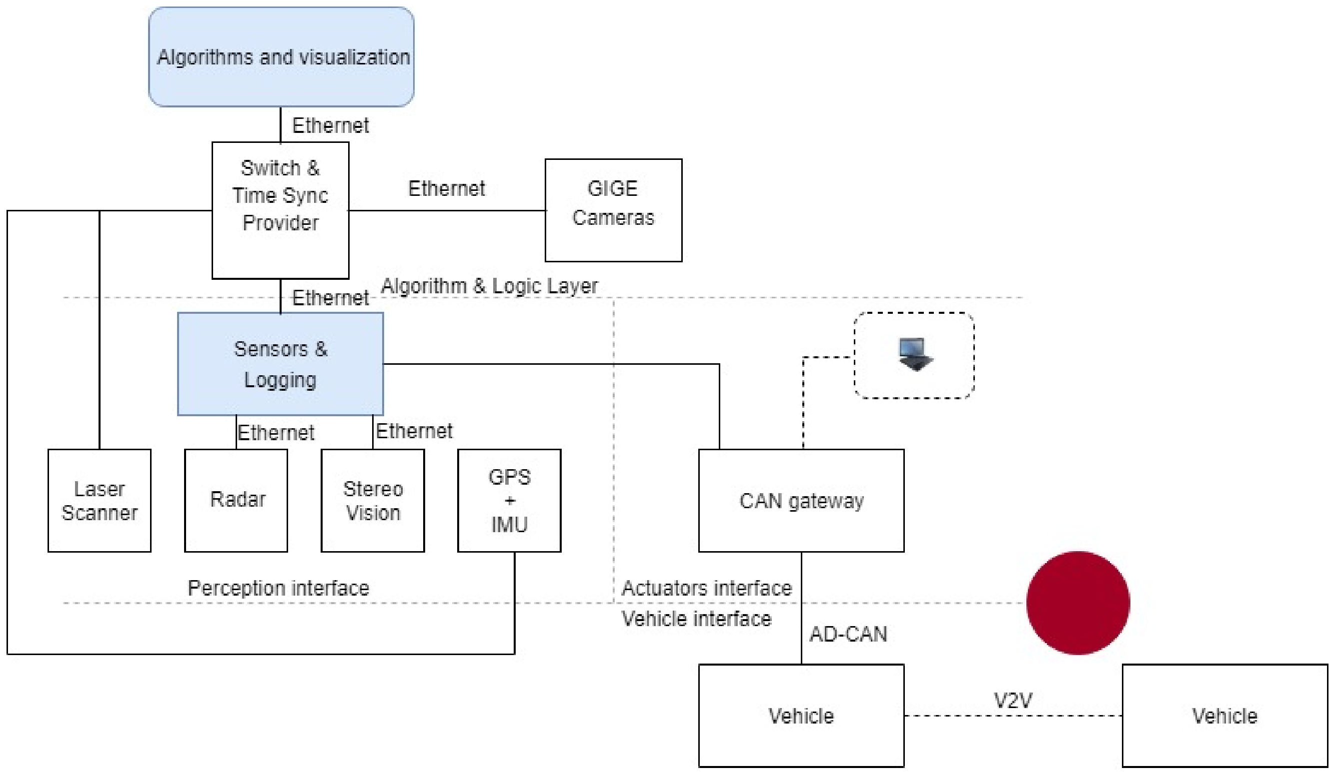


Figure 3: Vehicle Architecture

The vehicle is equipped with various sensors. The list is as follows.

Table 1: List of Sensors

Equipment	Type
Lidar	Velodyne HDI 32E
Stereo Cameras	Autoliv
Cameras	Axis M1124
GPS + IMU	Applanix LV V5
Ethernet Switchs	Cisco and Netgear
TimeSync	Meinberg M500
Radars	Autoliv
Industrial PC	AEC-6950
Comm Box	Kapsch EVK 3300
Radar PC + Storage	BRICK PC
Electronic Horizon	Autoliv Roadscape

Some of the sensors and controllers relevant to the experiment are briefly discussed in this report.

2.2.1 Joystick

Due to technical difficulties, joystick controlled automation had to be implemented instead of GPS based automation. The joystick was used to control only the lateral movements of the vehicle. As is the case with the controlling vehicle motion with joysticks, the motion was quite jerky compared to the smooth transitions of a computerized systems. A wired joystick similar to the image (figure 4) below was used for the experiment.

Figure 4: Joystick

2.2.2 GPS+IMU

The unit used in the vehicle is a combination of Global Positioning System(GPS)and Inertial Measurement Unit(IMU). The specific component, produced by Applanix is called POS LV V5 (Position and Orientation System for Land Vehicles version 5). It can deliver uninterrupted positioning and orientation of a moving vehicle in almost all environments. It is designed to provide positioning even in areas where GNSS signal is compromised or unavailable. It's a turnkey aided inertial navigation system. The component can handle a maximum data frequency rate of 200hz [6]. The component is as shown below(figure 5).

Figure 5: Applanix POS LV V5

2.2.3 TimeSync

The time and frequency synchronization module used in the vehicle is the Meinberg M500. The priority of the incoming signals can be set according to the needs of the users and also the bias value and a specification level for each source. The synchronization of time and frequency is very important in the experiment, as the data obtained is of different frequencies(from different types of sensors). Thus a synchronization device is an important device to have sensor fusion between different sensors of different frequencies.

Figure 6: Meinberg M500

2.2.4 Communication Box

Various technologies are infused together in the development of autonomous cars [11]. These communication devices help the vehicle see the world around them [11].The V2V (Vehicle-to-vehicle) and V2I (Vehicle-to-infrastructure) communication is taken care by the communication box in a vehicle. The communication box used in this vehicle is the Kapsch EVK 3300. It is an essential tool in development, integration and verification of complete in-vehicle V2X performance [7].

Figure 7: Kapsch EVK 3300

2.2.5 Eye Tracker

The eye tracker used for this experiment is SMI Eye Tracking Glasses (ETG) Natural Gaze^{TM}. The glasses are used as a tool to get insights into the human and computer interactions [15]. The glasses provide maximal peripheral perception and binocular vision, these two features are critical for depth perception and natural visual orientation. The glasses boast of a 60Hz robust binocular tracking technology and a high definition scene camera [15]. The glasses are as shown below (figure 8).

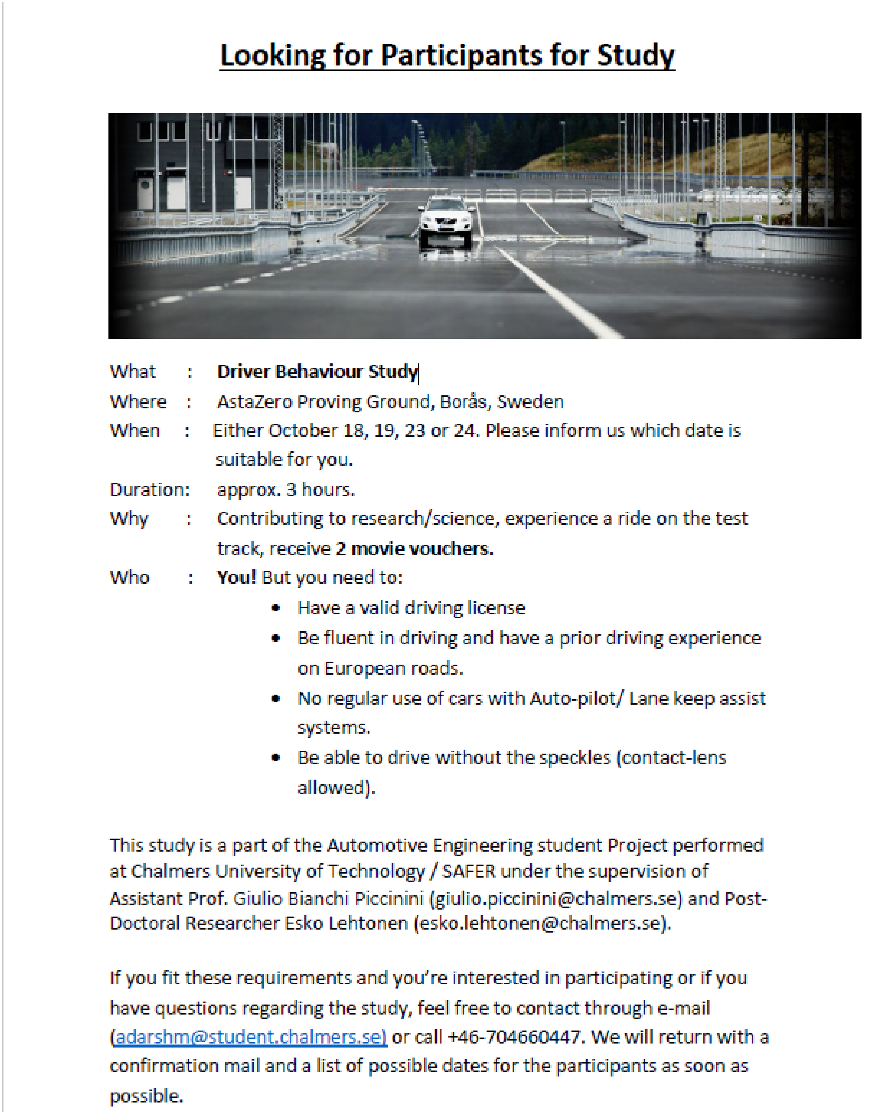
Figure 8: SMI Eye Tracker

2.2.6 OpenDLV

OpenDLV is an open source software based environment specifically designed to run in autonomous vehicles [14]. The software runs on the vehicle itself and it handles hardware communication, sensor fusion, decision making and visualization using various sensors and devices equipped on the vehicle. The software is written in standard C++. The focus of the software is on code clarity, portability and performance.

2.3 Participants

One of the main deliverables of the project was to collect driving and eye tracking data from participants. Participants were recruited for the experiment by advertising (Chalmers notice boards, leaflets at student apartments) and from participants of a previous QUADRAE (Quantitative Driver Behaviour Modelling for Active Safety Assessment Expansion) study conducted. Some of the requirements that the recruited participants needed to fulfill were that they needed to be able to drive comfortable without the use of lenses, not have fluency with driving with an assistance system and have a valid EU driving license. A sample of the leaflet that was circulated is shown in Figure 9.



Looking for Participants for Study

What : **Driver Behaviour Study**
Where : AstaZero Proving Ground, Borås, Sweden
When : Either October 18, 19, 23 or 24. Please inform us which date is suitable for you.
Duration: approx. 3 hours.
Why : Contributing to research/science, experience a ride on the test track, receive **2 movie vouchers.**
Who : **You!** But you need to:

- Have a valid driving license
- Be fluent in driving and have a prior driving experience on European roads.
- No regular use of cars with Auto-pilot/ Lane keep assist systems.
- Be able to drive without the speckles (contact-lens allowed).

This study is a part of the Automotive Engineering student Project performed at Chalmers University of Technology / SAFER under the supervision of Assistant Prof. Giulio Bianchi Piccinini (giulio.piccinini@chalmers.se) and Post-Doctoral Researcher Esko Lehtonen (esko.lehtonen@chalmers.se).

If you fit these requirements and you're interested in participating or if you have questions regarding the study, feel free to contact through e-mail (adarshm@student.chalmers.se) or call +46-704660447. We will return with a confirmation mail and a list of possible dates for the participants as soon as possible.

Figure 9: A snippet of the leaflet

The recruited participants were drivers who had a minimum of 30000km driving experience. The participants were people who drove a car on an average of 3 times a week. The volunteered participants were scheduled to drive in an instrumented car on the AstaZero test track on one of the four days booked, as per project budget and demands. Two participants would drive on each of the morning and afternoon sessions on one of the four days. Each participant was communicated, scheduled and allotted a given time slot and transportation arranged to and from AstaZero Proving Ground at Borås, Sweden. Some demographics of the recruited participants are as shown in Table 2.

Table 2: Demographics of Participants

Gender		Age				Type of car mostly used		
Male	Female	20-30	30-40	40-50	50-60	Estate	Sedan	Hatchback
9	3	3	2	6	1	4	5	3

2.4 Documents

As a part of the data collection process, there was a need to abide by the laws of data collection and data privacy. The documentation process involved two categories of documents. Procedural Documents which include Consent Form, Test Procedure, Test Instructions, Test procedure, Checklist. Second category of the documents include Questionnaire and Trust Scale, which was a tool to get a feedback from the participant.

2.4.1 Procedural Documents

The participants were supposed to agree to the terms of a **Consent form** (See Appendix - Figure 35) , by which the participant had officially given consent to be a participant in the test and is agreeable to use the collected data for research purposes. The consent form also informed the driver that the data will be secured and used according to the GDPR (General Data Protection Regulation).

The whole schema of the **Test Procedure** (See Appendix - Figure 36) was decided before hand to ensure a clear and consistent flow of tasks from the participant arriving at the test track up until the data collection and questionnaires. With this, the sequence of events to be conducted at the test track was consistent among team members and participants.

As soon as the participants arrived on the test day, a document of the **Test Instructions** (See Appendix - Figure 37) was distributed to them so that the participants were well informed about how to go about the driving task. This instruction manual also indicated that the driver will drive initially in a manual mode to get used to the system and then drive in the steering assistance mode.

A **Checklist** (See Appendix - Figure 38) was handed out to each participant for them to physically verify a few parameters, according to the test procedure. This checklist mainly consisted of safety measures and also for the participant to ensure the condition of the vehicle, such as tire state, surrounding environment, in-vehicle equipment, emergency buttons, etc) are intact. Each participant physically checked all safety parameters before the test.

2.4.2 Questionnaire

In order to collect data and feedback from the participants, and to understand the demographics of the participants, a questionnaire and a trust scale was provided to each participant.

A **Trust Scale** (See Appendix - Figure 39) was handed over to every participant after every lap of driving in order to understand their trust in the system and the work load of driving task. Also, once all the laps were concluded a detailed **Questionnaire** (See Appendix - Figure 40) was handed out to each of the participant in order to understand few details such as, most frequently used vehicle, their preference and exposure to auto pilot system, their trust on the autonomous system, etc.

All the above documentation was maintained and performed meticulously through the course of the data collection sessions for each participant. This sets a framework for not only maintaining a consistent test procedure for each participant, but also to get a similar pattern of data collected.

2.5 Procedure

The section describes the procedure followed during the pilot and main session.

2.5.1 Pilot session

Figure 10 describes the procedure for setting the vehicle in the steering assistance mode.

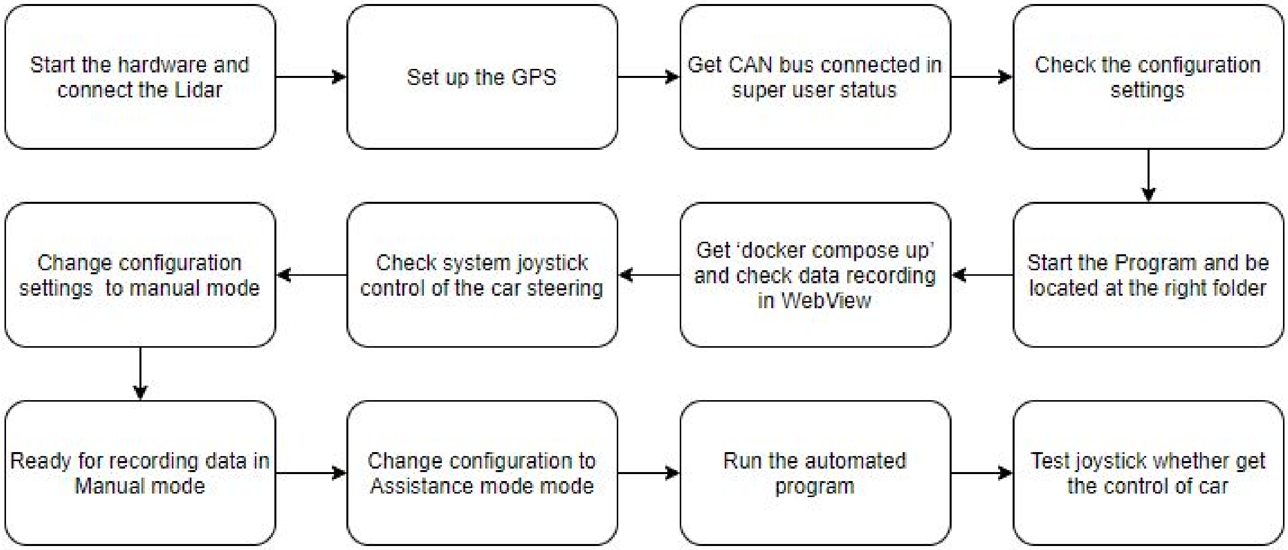


Figure 10: Block diagram representation of the procedure for setting up the steering assistance mode

The procedure followed by each participant during the pilot session is listed below:

- Brief description of the overall driving exercise.
- Calibration of eye tracker by using reference points/nodes.
- Driving one lap of the track on manual mode to get accustomed to the vehicle.
- Calibration of the eye-tracker again, in order to compensate for any biases in the recording if any.
- Start recording the vehicle parameters and eye-tracker data while driving the vehicle in manual mode.
- Calibration of the eye-tracker after the completion of the lap.
- Start the steering assistance software and simultaneously start recording the vehicle and eye-tracker data.
- Calibration of the eye-tracker after each lap.
- After completion of the driving exercise, obtaining feedback from the participant about the driving experience with the steering assistance software.

One fundamental difference between the manual driving and steering assistance driving is that, in the former mode the participant has to accelerate and steer the vehicle manually while in the latter mode the Cruise control system maintain the vehicle on the set speed limit and the steering assistance system maintains the lane position of the vehicle with the participant having to supervise the system.

2.5.2 Main session

After recruiting the participants a schedule was drafted. While making the schedule, the participants were allocated slots in their preferred timings. Each day, a maximum of 4 participants were allocated the slots to complete the session. On each day, after the participant reached the test track the procedure described in figure 11 was followed.

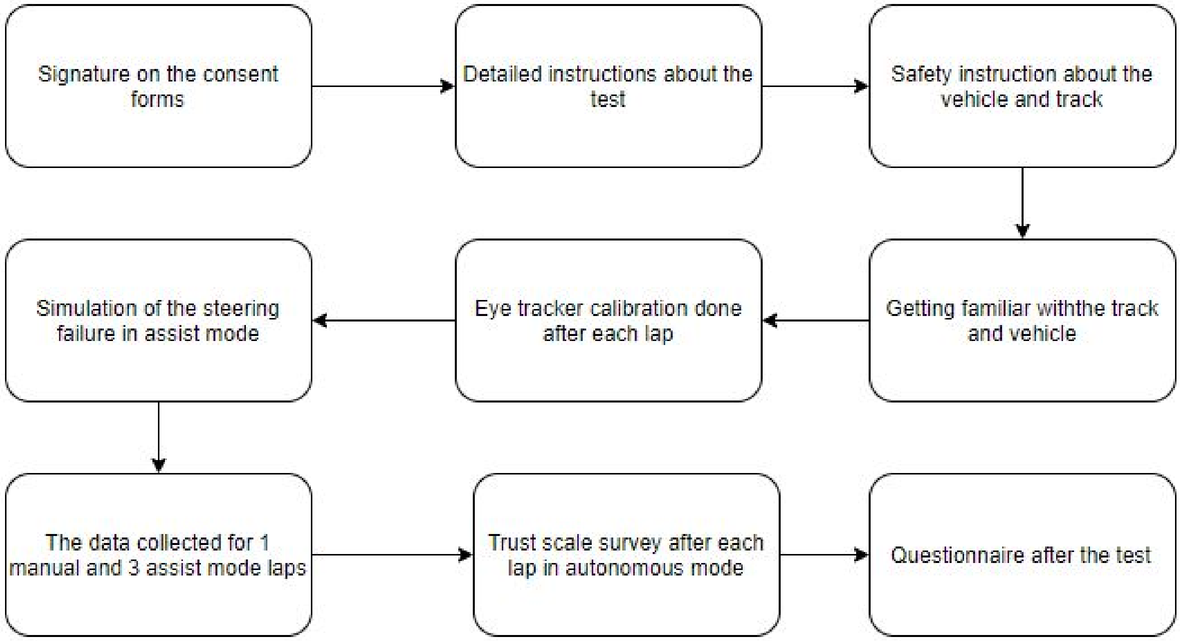


Figure 11: Test Procedure for main session

The participants gave their informed consent to participate to the experiment. It was important in our experiment as it was an official permission for work with the data recorded during their driving. Next the participant were given instruction about the driving exercise and their task. Before beginning the test, the participants were given a tour of the vehicle. They were informed of the equipment that was used in the vehicle for the study.

One important feature of the experiment was that at any point of the test, the participant could override the steering inputs of the experimenter. This meant that the experimenter would provide an actuation request which could be overridden by the participant driver at any point in the steering assistance driving mode.

Also, the participants were informed about their action in case of an emergency. The vehicle has 2 emergency stop buttons. Activating one of them switches off the vehicle engine and stops the car while the other cuts the contact between the software driving the car and vehicle. The second choice is used when the driver does not feel comfortable using the assistance driving. Switching-off the vehicle engine stops the data recording and needed to be used only when absolutely necessary.

Additionally, the instrumented vehicle was fitted with an in-vehicle camera. The main intention of this was to record the hand position of the participant on the steering wheel and capture the steering response of the driver for different actuation requests. Separate recording were created for manual mode and steering assistance mode.

Each participant, after completing the documentation and receiving the test instructions, drove out the vehicle from the garage and completed one lap of the track to get used to the vehicle and the track. Then the participants were provided with the eye-tracker. Next the eye tracker was calibrated according to the vision of the participant. Next the participant completed one lap around the track in manual driving mode. The eye-tracker software made a recording of the eye positions of the participant while they drove around the track. Simultaneously a recording of the vehicle parameters for example speed, GPS position, heading, actuation and steering requests etc. were also made. While driving in the manual mode both the longitude and the latitude control of the vehicle are controlled by the participant. After the completion of the lap, the eye tracker was again calibrated to the participant vision to account for any changes that occurred during the driving lap and the eye-tracker and vehicle data recording were stopped.

For the next lap, the recording were started again and the experimenter seated at the back took control of the steering to simulate the steering assistance software. The participant drove the vehicle up-to a speed of 60 km/h (40 km/h for on 18^{th}) and then activated the Cruise Control (CC) which controls the longitudinal position of the vehicle and ensures the vehicle maintains the set speed. For the first lap in steering assistance mode, the experimenter drives the vehicle within the track lane and maintains the position of the vehicle. After the completion of the first lap, the eye tracker are calibrated and the recording is stopped.

For the next lap, the recording were started again and the participant accelerated to the required speed and then activated the Cruise Control system. For this lap the experimenter drove the vehicle out of lane at Curve 1, simulating the failure of the steering assistance system. The eye-tracker recorded the eye movement patterns of the driver during the system failure which would be investigated in the data analysis phase of the study. Similarly the experimenter simulated the system failure at Curve 2 in the next lap and Curves 1, 2 and 3 in the last lap and the corresponding response of the participants were recorded. While the eye-tracker recordings were stopped after each lap and started again at the beginning of each new lap, the vehicle data and the in-car videos were recorded together for the steering assistance mode. Also, after the completion of the each lap in steering assistance mode, the participant were required to fill a feedback form about the driving task which would rate the workload and trust in the steering assistance laps.

At all points of data recording process, and especially after each lap, a critical activity was to ensure that the data has been recorded on the server. Data from all sensors were connected to the main computer of the car which was in turn linked to the Revere server. A documentation of the file numbers of the recorded data along with the quality of the eye-tracker data were made which would be useful later in the data analysis stage. After the completion of the test, the participant were required to fill a questionnaire that recorded their response about the driving task in general and their feedback about their trust on the steering assistance system. After the completion of the driving exercise, the participants were explained the motivation behind the study.

2.6 Analysis

2.6.1 File Conversion

The entire course of data collection involved data from different sources being continuously logged onto a server. The instrumented vehicle was loaded with sensors(Lidar, GPS, Radar, camera) in order to record the paramters during the drive. The data from the sensor (predominantly the GPS signals) was directly retrieved by logging it on the server. On the other hand, the data from the core of the vehicle, was logged separately. Some of the parameters that were recorded during this experiment were vehicle speed, vehicle acceleration, steering wheel angle and the actuation request signal from the joystick. The data from the externally loaded GPS sensor was downloaded and categorized as 'standard' data. The CAN data from the vehicle, categorized as 'special', needed to be converted into a format that can be analyzed. For the same, a *.odvd* file is used to convert the vehicle data to a .rec format. The *.odvd* file is added on the OpenDLV interface and this conversion yields a *.rec* file. This *.rec* file can now be downloaded from the server. The downloaded *.rec* file can then be converted into a *.csv* format. The *.csv* format file contains the values of all the parameters. MATLAB was used to filter and sort the data.

2.6.2 Vehicle data analysis

The vehicle data contains the information of different parameters recorded for the time the vehicle is being driven on the track. By analysing the vehicle data, an estimation can be made as to how the participant responded for the track conditions and the behaviour for lane drifting scenarios.

The first step in vehicle data analysis was to import all the parameters into MATLAB and save the files in .mat file structure which would be used in the further steps. Next a MATLAB script was written to analyse the data in step by step approach. All the .mat files were loaded one after the other and values of the parameter along with the time stamps were copied into a new struct.

However, each of the parameters in the .mat files contains the data at different time stamps. This means that even though all the parameters are recorded between the same time duration, the time stamps at which the data for each of the parameter is recorded is different. Due to this, the size (length) of the all parameters are different. Therefore, it was essential to convert all the data into a common time stamp. Among all the parameters, the steering actuation had the smallest time stamp (0.010 s) and the steering wheel angle had the largest time stamp (0.044 s). Hence the time stamps of all the parameters were scaled down to the time stamp of the steering wheel angle. This common time-stamp data was stored into a new struct file.

The data at this stage still had data recorded for all the three steering assistance mode together which needed to be separated. Vehicle speed is the parameter that was used to separate the three steering assistance mode laps from the combined data. This meant that, after the recording were started the first time the vehicle speed reached zero was considered as lap 1 and from then on to the second time was considered as lap 2 and similarly for lap 3.

Figure 12 shows the initial data obtained just after the conversion .REC to .CSV format. At this stage different vehicle parameters have different time stamps and are not lap classified.

Speed	1x85077 double
S_Time	1x85077 double
Speed_time	1x85077 double
Latitude	1x85674 double
Longitude	1x85674 double
P_Time	1x85674 double
GPS_time	1x85674 double
Steering	1x165302 double
A_Time	1x165302 double
Actuation_time	1x165302 double
SteeringWheelAngle	1x38068 double
St_Time	1x38068 double
SWA_time	1x38068 double
GPS_time_new	1x85674 double

Figure 12: Initial vehicle data

On the other hand, figure 13 shows the data after having a common time-stamp and separated into different laps.

Time_stamp	Speed	Latitude	Longitude	Steering	SteeringWheelAngle
1x8416 double	1x8416 dou...	1x8416 dou...	1x8416 double	1x8416 dou...	1x8416 double
1x8886 double	1x8886 dou...	1x8886 dou...	1x8886 double	1x8886 dou...	1x8886 double
1x9110 double	1x9110 dou...	1x9110 dou...	1x9110 double	1x9110 dou...	1x9110 double

Figure 13: Common time-stamp, lap classified vehicle data

2.6.3 Eye behavior analysis

Due to the limitation of eye tracker equipment, weather and also the influence of movement of driver's head on eye tracker equipment, the accuracy of eye tracker results was not always reliable. For some recordings, fixation point could be missing for a long time and it's not possible to make any analysis. Also based on the calibration result, it showed that when the lap was finished, big bias occurred for fixation. And it's difficult to know when the bias happened for the test lap and fix the offset. Therefore from all 10 participants' eye tracker results, two with good quality and accuracy were picked based on the calibration tests shown in the eye tracker video. They are participants A and B, and all the analysis were made based on their tests. The next sections include: the eye tracker software BeGaze, choice of map, mapping method and analysis approach.

2.6.3.1 BeGaze software

The SMI software BeGaze was used for checking, post-processing and showing the eye behavior data. BeGaze is eye behavior software and distributed in various variants for variety of research needs. For the professional version, it offers the full range of program features to analyze and export eye tracking data for still images stimuli, without any restrictions concerning the number of subjects or stimuli. In BeGaze the process of the measurement data is shown as the following steps [16]:

- Collect and assemble all data which belong to one experiment.
- Select an analysis, its data sources (stimulus, subjects, time interval).
- Modify single or multiple dimensions of the data source to adapt the analysis.
- Roll over a selection of data sources to the next analysis for a different perspective or drill down.
- Evaluate, export and/or print diagrams or data.

Within BeGaze, we could replay the eye tracker video, map with different stimulus for different analysis purposes and check the eye behaviour properties based on mapping.

2.6.3.2 Manual Annotation

Annotations were done by using the function 'semantic gaze mapping' in beGaze. As shown in the figure 14, the original video is shown in the right side and the reference view is shown in the right side. Therefore, it's important to find one sensible reference view.

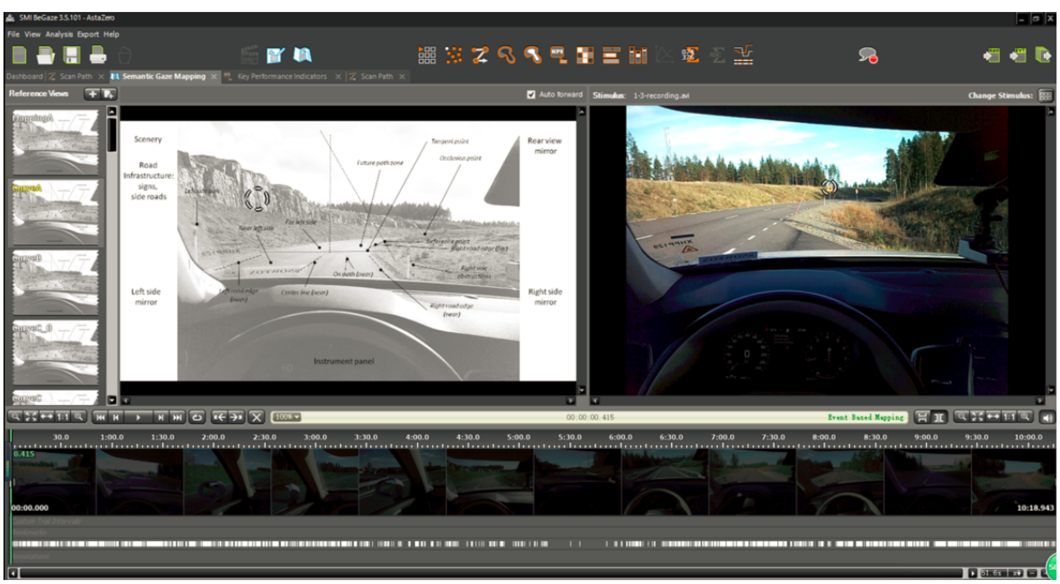


Figure 14: Semantic Gaze Mapping

As the study is about driver steering behavior, the analysis is also focused on the curves. To do the mapping for eye tracker video, a picture which shows car front view in rural road curve was chosen as the map. To classify where the driver was looking at, the map from 'Systematic Observation of an Expert Driver's Gaze Strategy' [17] was also partly adopted. Its map was divided into different zones and lines including: scenery, road edge, side mirrors, other road users, lane edge, instruments, far road, lane center, road signs, intersections and rearview mirror. The first map we used was based on it and it was discerned between near and far zones as shown in figure 15. The near and far zones were distinct by tangent point.

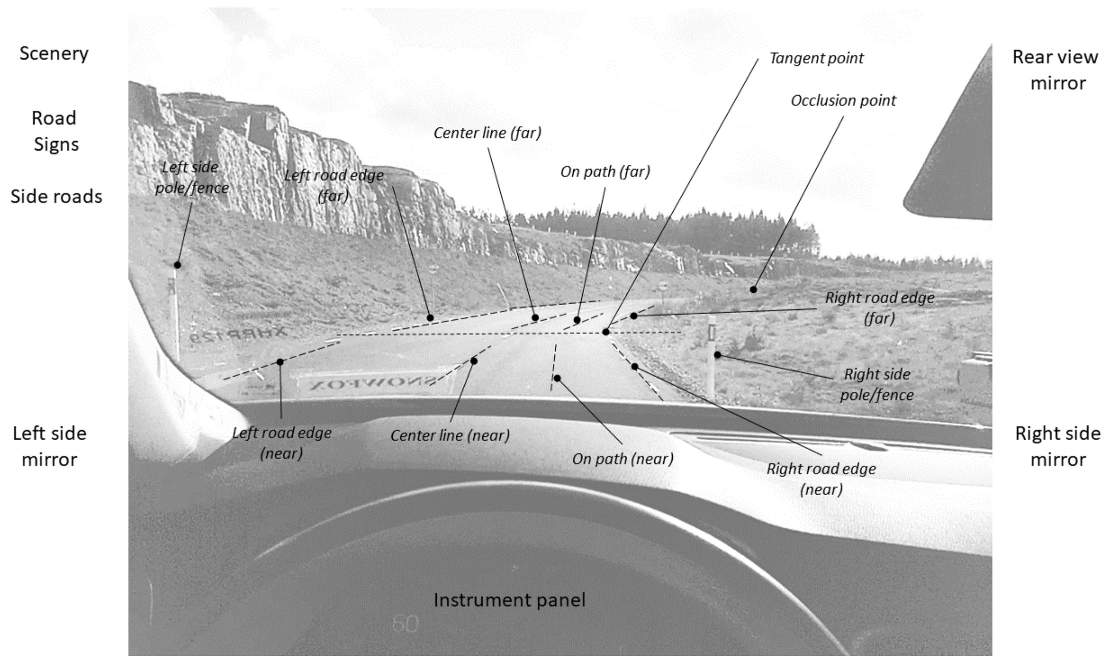


Figure 15: Initial Map

However, during the time for mapping, it was almost impossible to distinguish the far zone areas among left road edge, center line and on path as they are so close to each other than the near zone areas. Also, some eye video showed that the driver didn't look in the far zone that frequently. Thus far zone areas were redefined in some other maps by combining different areas into future zone. And the final map was chosen and shown in figure 16 according to the mapping experience.

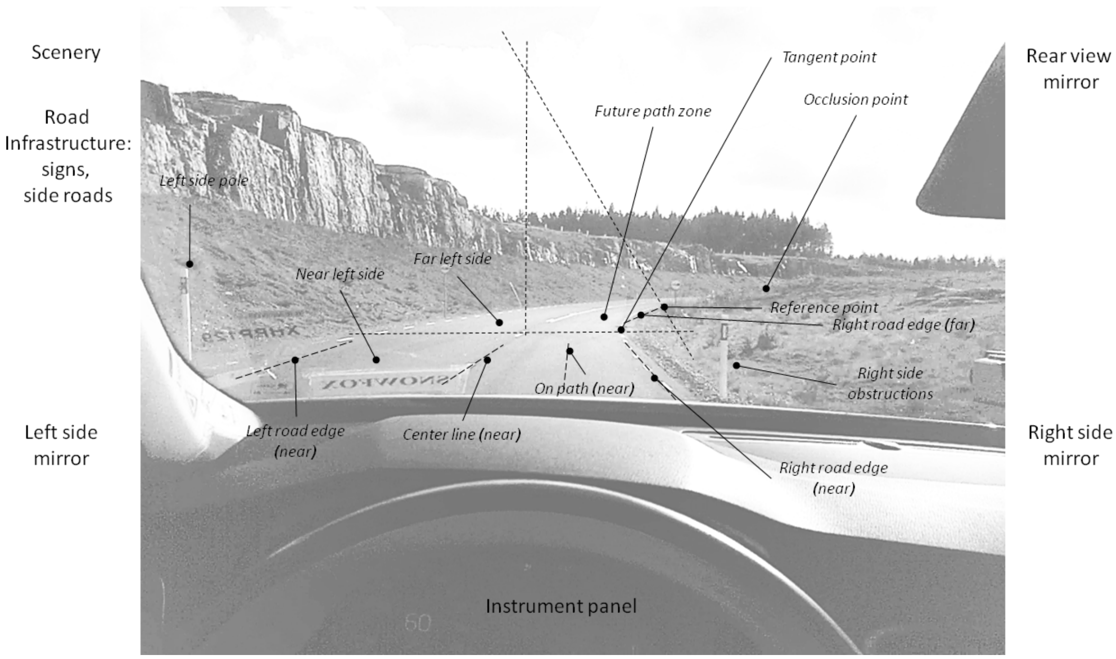


Figure 16: Final Map

Tangent point is used to divide between near and far point. The near zone contains: left road edge, near left side, center line, on path and right road edge, while the the far zone has far left side, future path zone, tangent point, right side edge, reference point and occlusion point. The reference point is chosen as some left edge point in the far zone to distinct future path zone and occlusion point. Besides, the map also includes zone inside car as instrument panel, and zones outside car as scenery, road infrastructure signs, side roads, left side mirror, right side mirror and rear view mirror.

Even the zones of map is cleared defined and shown in the figure 16, as the limitation of the accuracy of eye tracker and the gazing point is a small 'gazing circle' instead of one point, it's still confusing sometimes when doing the mapping. Besides, mapping could be quite subject and the results would not be so reliable. Therefore, some general rules were defined by us and it's shown as following:

- Everything beyond tangent point is far zone.
- Everything inside car belongs to 'instrument panel'.
- Current gazing point is related to the next points.
- Near center line is defined when the gazing point crosses the center line.
- Right road edge near is defined when the gazing point crosses the right road edge.
- Everything on the right edge beyond the tangent point belongs to right edge far.

2.6.3.3 Mapping method

The choice of mapping method depends on what results are needed for the study. Precise mapping works well for 'scan path' and 'Bee Swarm' analysis on a screen shot of photo for the video, while if 'KPI', 'AOI(Areas Of Interest) Sequence chart', 'Binning Chart' etc are needed, AOI mapping could be applied as it's easier and faster to map. AOI mapping creates visualization on a realistic reference view and labels mappings on object image or words. The mapping method used for this study was mainly AOI mapping and the AOI map is shown in figure 17.

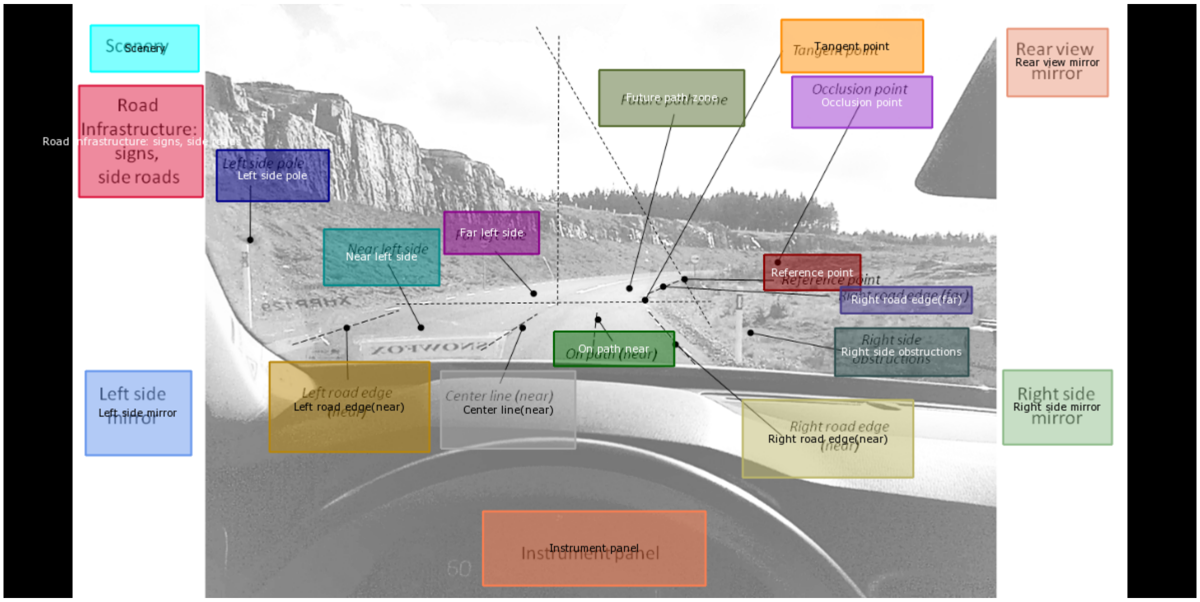


Figure 17: AOI Map

The stimulus for AOI map is the chosen map and AOI areas were selected by rectangle blocks. For semantic gaze mapping, mapping as done with the chosen map. Map didn't show the AOI areas and AOI mapping was done by clicking around the words area for each frame of the video. The processes of mapping took quite long time because it was done by frame to frame manually.

2.6.3.4 Analysis approach

For the analysis, the Gaze Replay data view shows gaze positions and eye events for the selected subject plotted over all the stimuli included in the experiment. This is useful for us to get an overview of the driver's eye behavior during the recording of the experiment. And it was used to check the eye tracker data quality and accuracy. After the manual annotation was done based on the AOI map, the AOI Sequence Chart was used to show the temporal order at which AOIs were hit by a particular subject. From it, eye fixation statistic results could be shown intuitively.

First manual laps were manually coded for the two chosen participants. Then according to the vehicle data results and in car video, specific deviation time was found for coding the steering assistant laps. From the AOI Sequence Chart, results for different laps could be compared.

3 Results

This section will present the results obtained from the analysis of the vehicle and the eye tracker data.

3.1 Vehicle Data Analysis

Figure 18 and figure 19 show respectively the path traced by the vehicle on curve 3 while making a lap around the track in both manual and steering assistance mode. Both the plots represents the path traced by participant A.

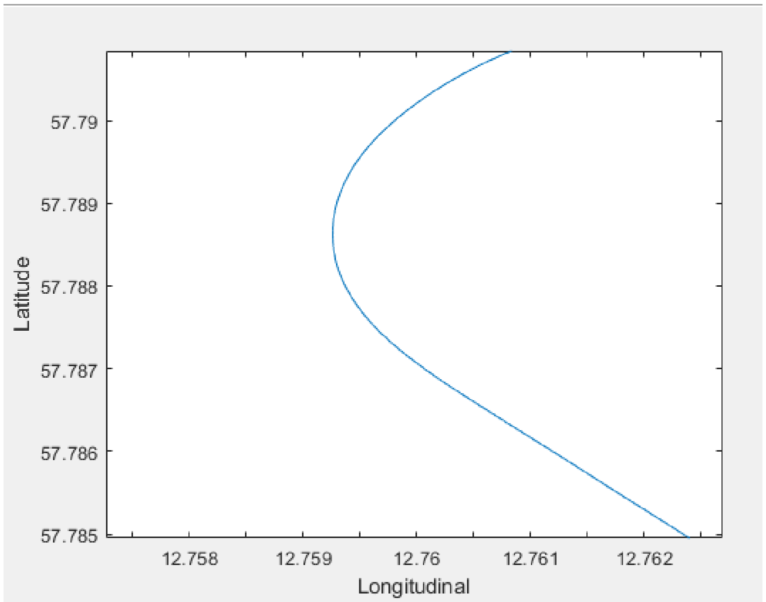


Figure 18: path traced on curve 3 in manual mode

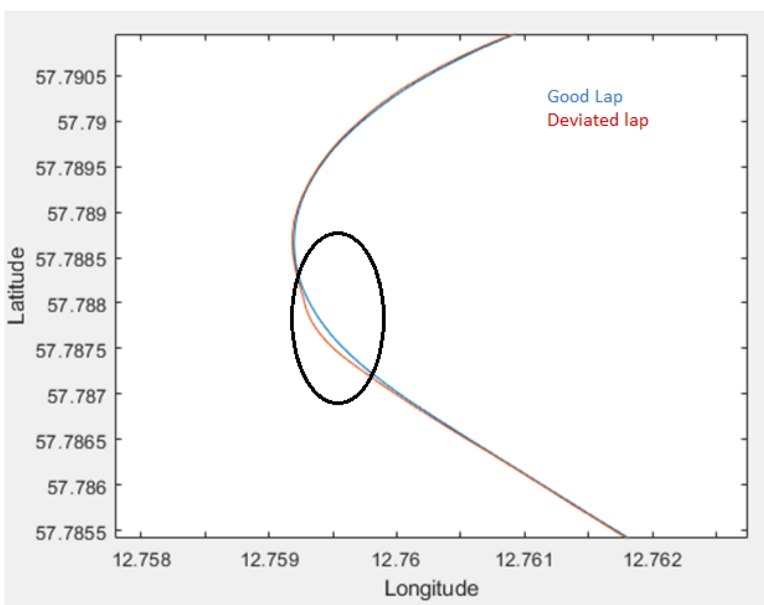


Figure 19: paths traced on curve 3 in steering assistance mode

Figure 19 shows the different paths traced by the vehicle in steering assistance mode. The blue line represents the lap when the vehicle stay within the lane and the red line represents the lap when the vehicle drifts out of lane. It means that when a deviation is indented, participant A allowed the vehicle to drift off the lane.

Figure 20 and figure 21 show respectively the speed attained by the same participant during driving the vehicle respectively in manual and steering assistance mode. A note to be made is that, as on the first day of experiment, the experimenter wasn't sure about the performance of the joystick controls and therefore the vehicle in steering assistance mode was run close to 11 m/s (40 km/h).

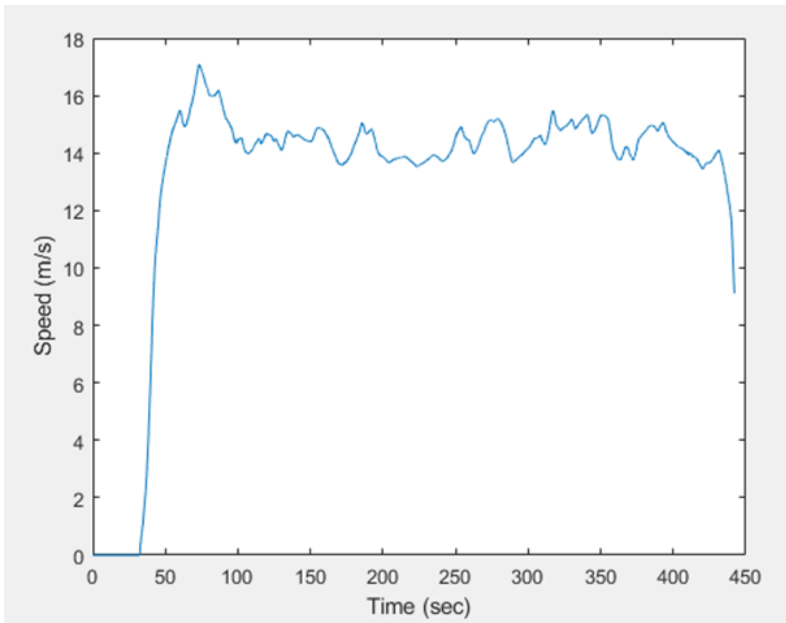


Figure 20: speed vs time in manual mode

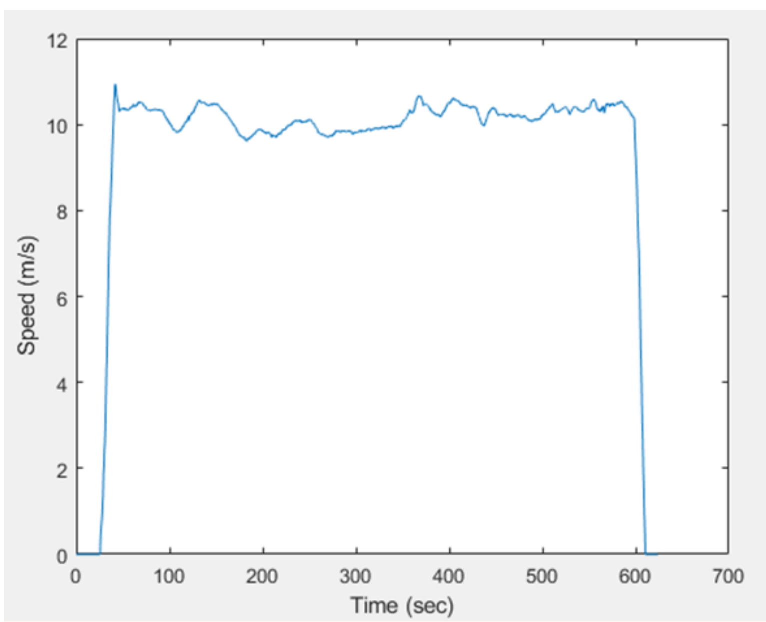


Figure 21: speed vs time in steering assistance mode

The speed in the manual driving mode fluctuates as the speed is controlled manually by the participant while in the steering assistance mode, the cruise control system regulates the speed and hence the speed is more stabilized.

Figure 22 and figure 23 show respectively the steering wheel demands in manual and steering assist mode. The high variability observed in case of assist mode is due the fact that the joystick was used to provide steering inputs to the vehicle, and each time after providing the input with the joystick, the steering wheel angle dropped to 0 degrees.

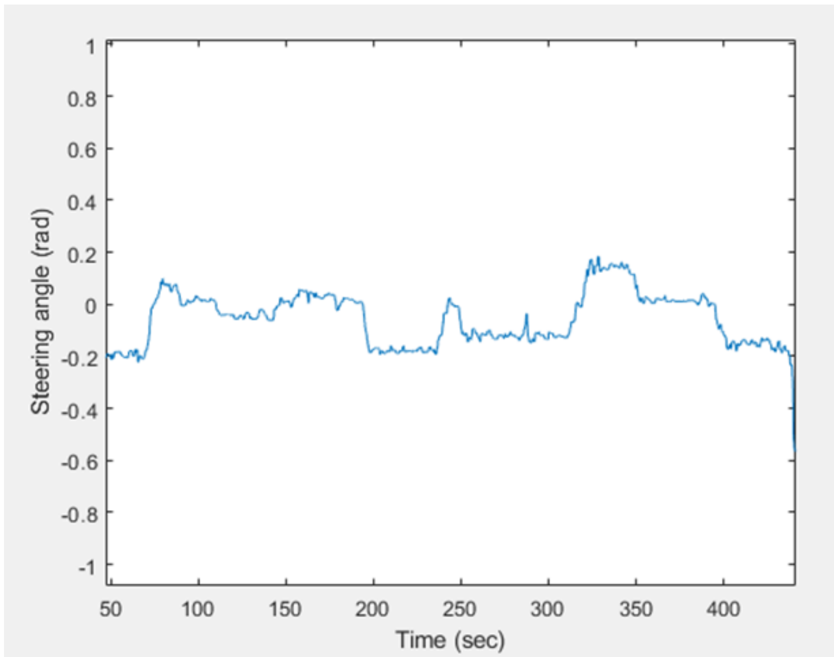


Figure 22: steering wheel angle in manual mode

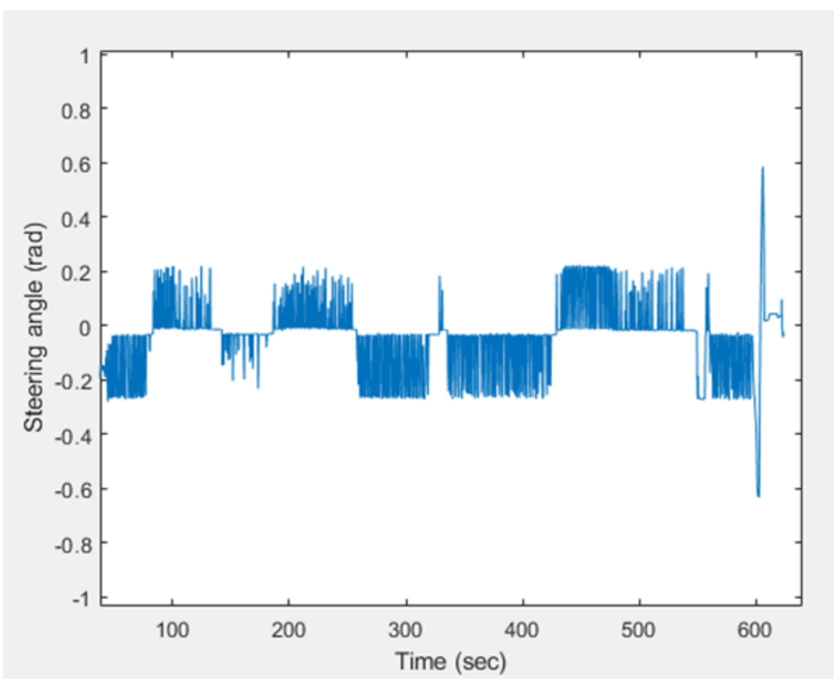


Figure 23: steering wheel angle in assistance mode

The steering inputs for assistance mode is slightly higher from manual mode due to the fact that the vehicle was moving at a lower velocity in the assistance mode and hence a slightly higher steering angle was required to turn the vehicle in case of assistance mode.

Figure 24 and figure 25 show respectively the actuation request and steering wheel angle in steering assistance mode for the participants A and B. The blue line represents the actuation request provided using the joystick and the red line is the amount steering angle input.

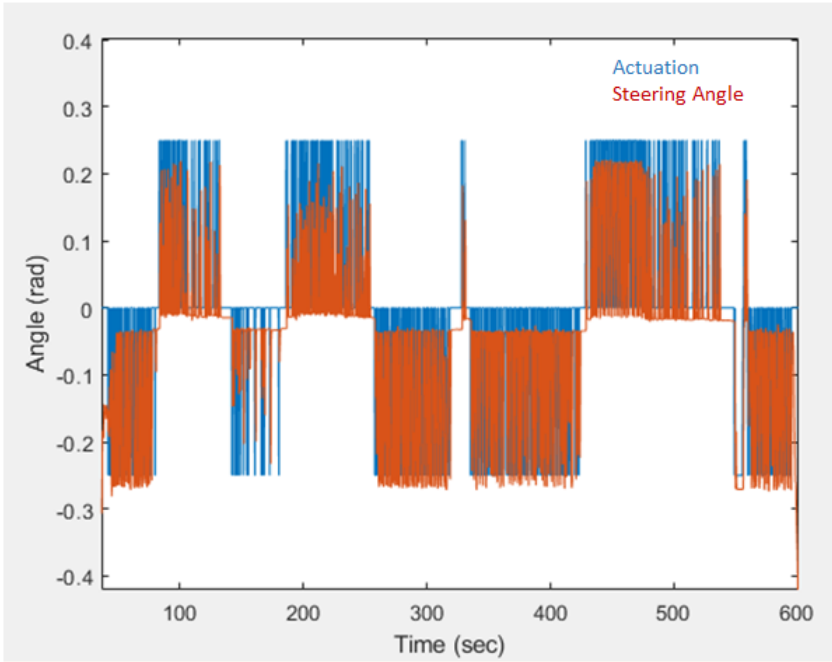


Figure 24: Actuation & Steering wheel angle in assistance mode for participant A

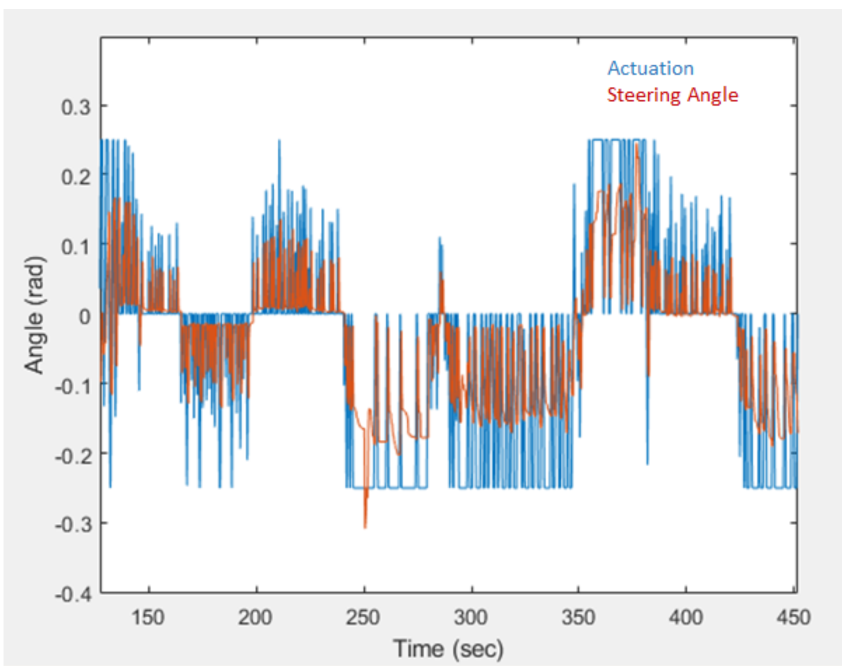


Figure 25: Actuation & Steering wheel angle in assistance mode for participant B

Figure 24 shows that the steering angle input for the vehicle for participant A is almost equal to the actuation request. This means that the participant allowed the vehicle to steer as per the actuation requests of the experimenter and didn't limit the steering. On the other hand, from figure 25 it can be seen that the steering angle input for the vehicle for participant B doesn't vary according to the actuation request initiated by the experimenter which in turn implies that the participant limited the steering of the vehicle.

3.2 Eye Tracker Gaze Analysis

Figure 26 and figure 27 shows respectively the gaze fixations of the participant A and B while driving the vehicle in manual mode.

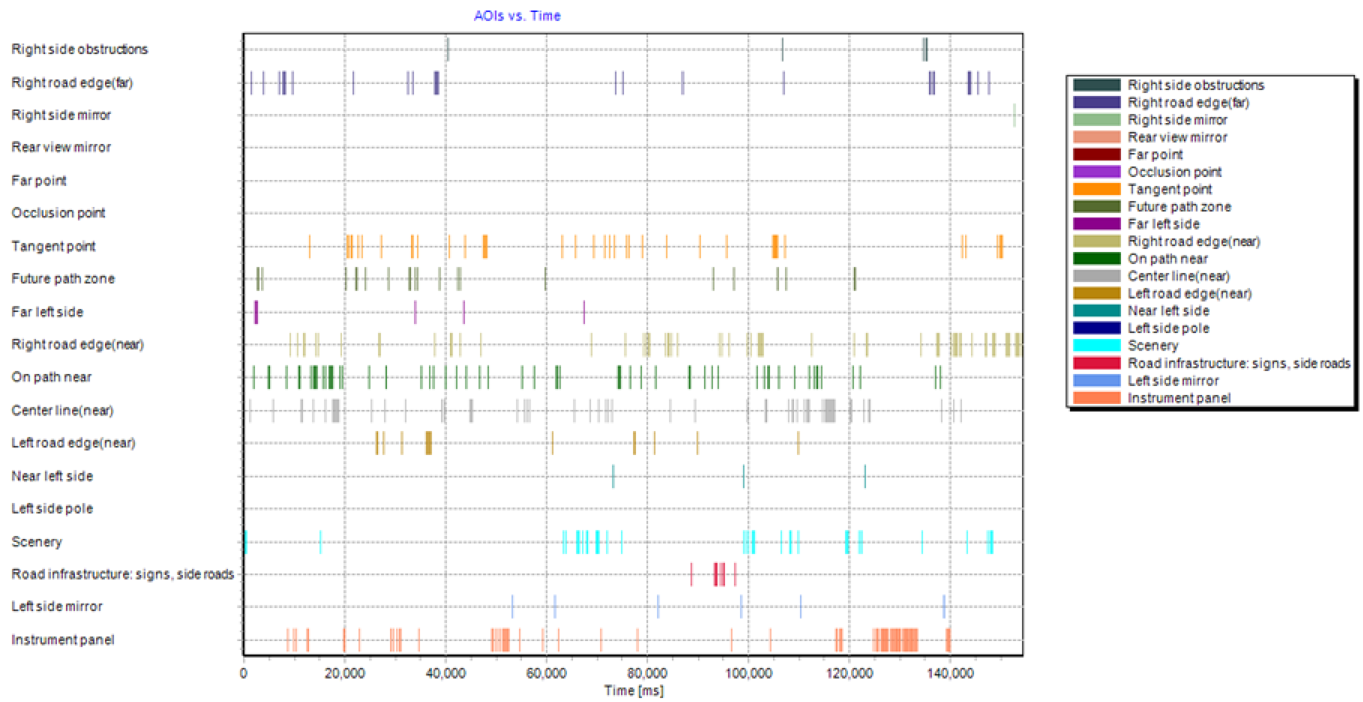


Figure 26: Gaze Fixation in Manual mode for participant A

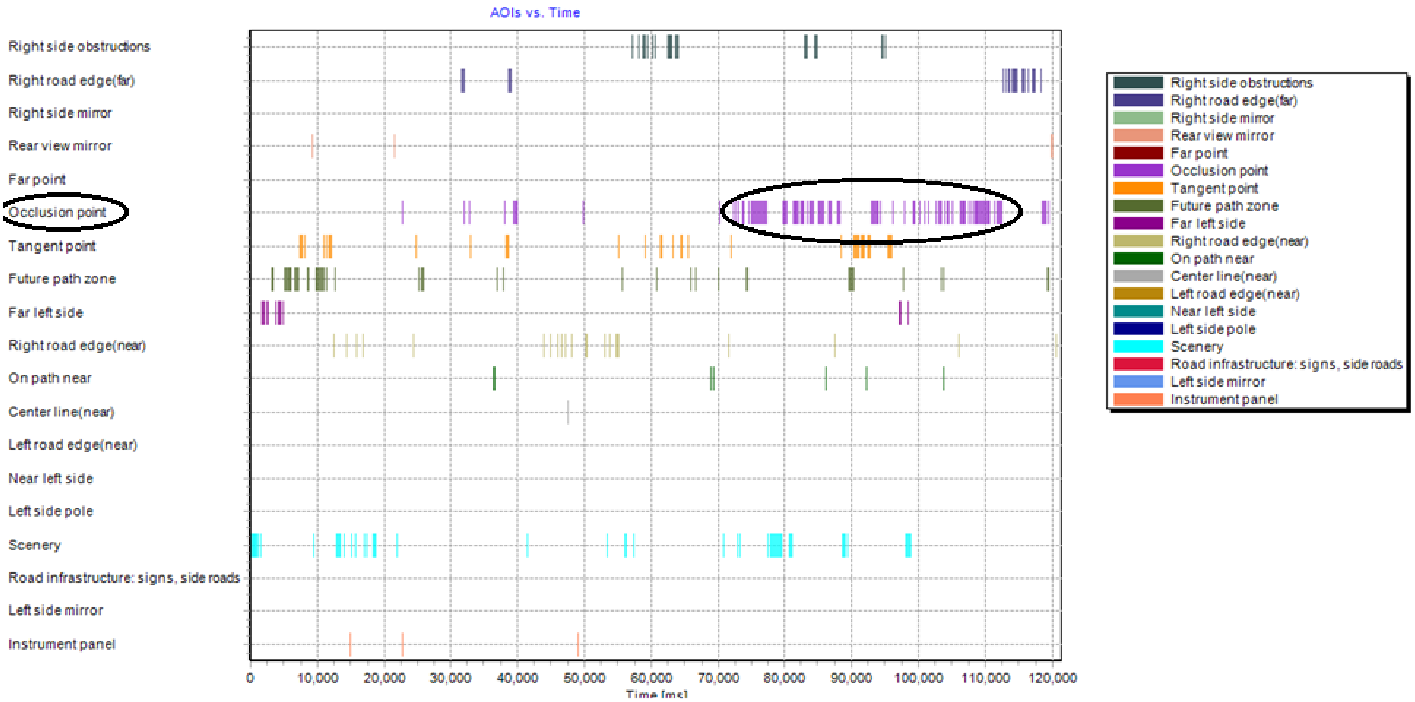


Figure 27: Gaze Fixation in Manual mode for participant B

The participants A and B mostly had their gaze fixated on the road and sometimes on the scenery in manual driving mode. Also, the blank spaces were the instances for which the eye tracker did not record the data. The gaze patterns for participant A suggests that gaze fixation was almost evenly distributed with the driver glancing all spots. However, the gaze of participant B suggested that the participant eyes were fixated on the occlusion point for a long duration. Occlusion point is the farthest visible point to the driver. Also, a few fixations of glances of scenery were recorded for participant B during the lap.

3.3 Vehicle Data - Eye Tracker Combined Analysis

The figures below show the scenario of the failure of the steering assistance system in lap 2 at curve 3 of the track for participant A and the corresponding gaze fixation for the duration. Figure 28 shows the deviation of the vehicle from the lane. The blue line represents the lap around the track with the vehicle staying within the lane while the red line represents the lap with deviation. Figure 29 shows the plot of joystick actuation and the steering angle request Vs time. When a vehicle approaches a right curve, the steering wheel needs to turn right to maneuver the curve. However to simulate the failure of the steering assistance system couple of actuation inputs were given to turn steering wheel towards the left side. After this, there were no inputs provided and the participant was expected to respond to the simulated system failure. As there were no inputs from the participant another input was given to pull the vehicle further off the lane. However, as the participant didn't provide any steering inputs to pull the vehicle back into the lane, the experimenter had to get the vehicle back into the lane using the joystick actuation. From the in-car camera video, it was seen that the participant almost placed the hands on the steering wheel when the vehicle was completely out of lane, but retracted immediately and provided no steering inputs to pull the vehicle into the lane. This clearly shows that the driver trusted the system to steer back automatically during such a failure situation.

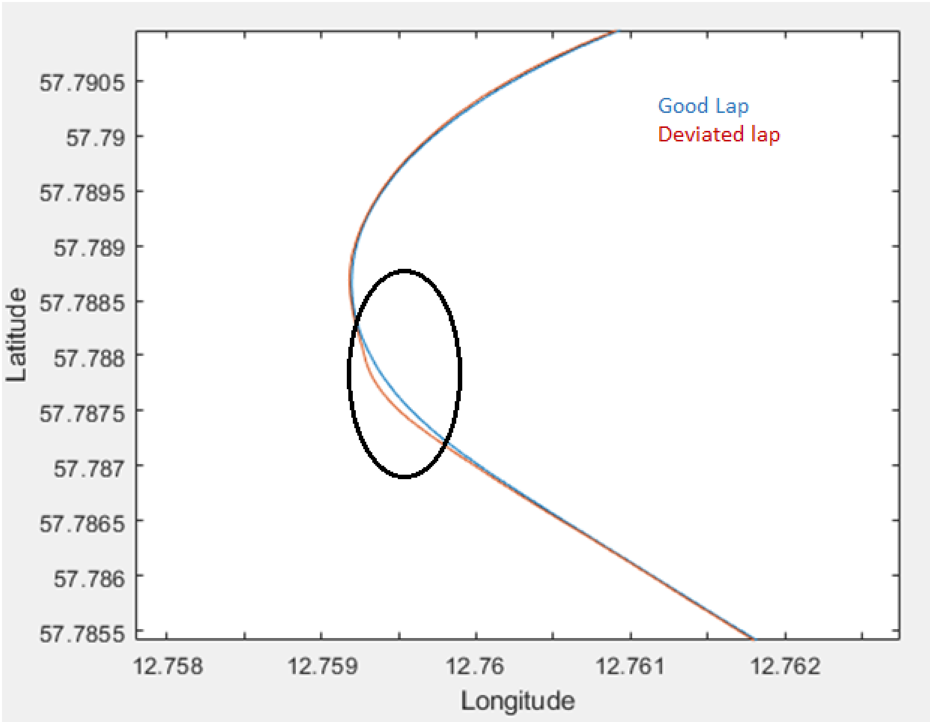


Figure 28: Assistance mode GPS position in Curve 3 for participant A

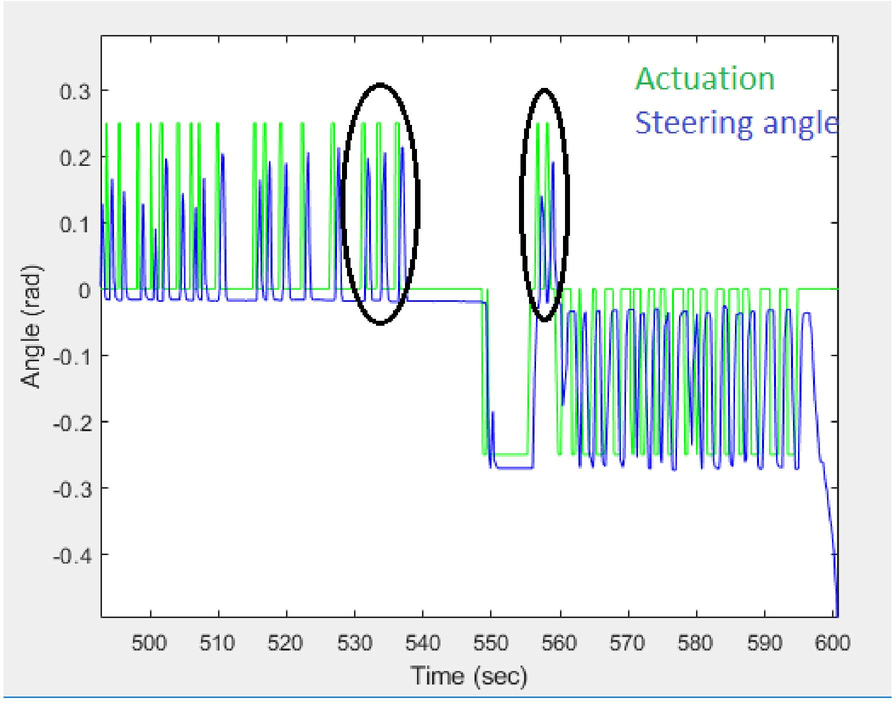


Figure 29: Assistance mode Actuation & Steering angle in Curve 3 for participant A

Figure 30 show the gaze fixation of the participant for both the laps in steering assistance mode with the deviation occurring in lap 2. The blank spaces in the gaze fixation plots are the duration for which the data is not captured. At the instance of the failure of the system, the participant gaze was concentrated on the instrument panel and the near left side.

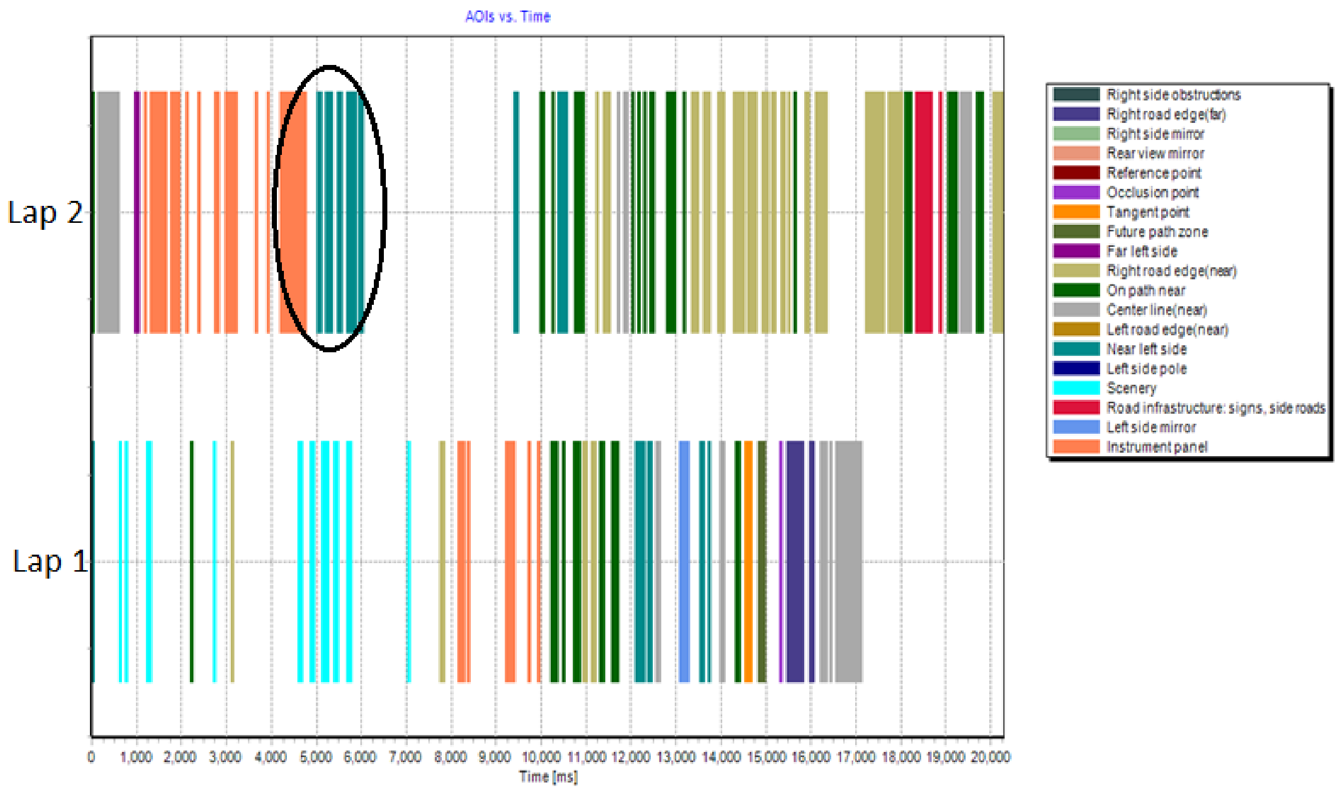


Figure 30: Eye Fixation of participant A

The figures below shows a similar scenario of the failure of the steering assistance system in lap 3 at curve 3 of the track for participant B and the corresponding gaze fixation for the duration. Figure 31 shows the deviation of the vehicle from in-lane path. The blue line represents the lap around the track with the vehicle staying within the lane while the red line represents the lap with deviation. Figure 32 show the plot of joystick actuation and the steering angle request Vs time. Similar to the previous scenario, the curve turns to the right and the steering wheel needs to turn right to maneuver the curve. However to simulate the failure of the steering assistance system couple of actuation inputs were given to turn steering wheel towards the left side. As soon as the actuation is given, the participant intervenes and regains control of the steering wheel. This implied that the participant was concentrating on the driving task and monitoring the system well. This fact was supported by the in-car camera video. It showed that the participant was constantly correcting the steering actuation to prevent the vehicle deviating from the lane. Also, during the system failure, the participant provides steering inputs to pull the vehicle into the lane as soon as the vehicle departs out of the lane.

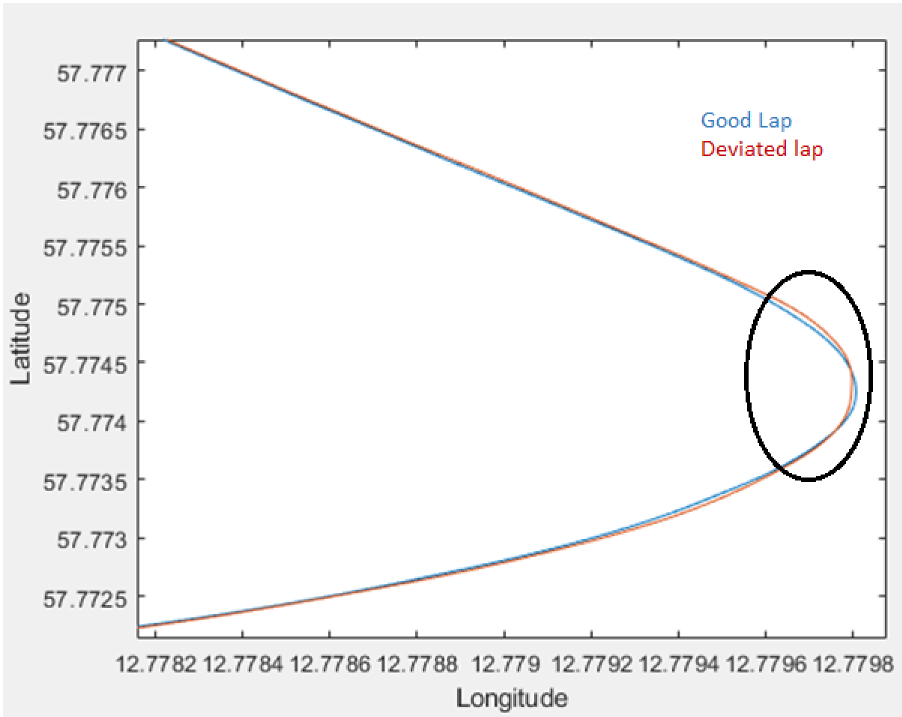


Figure 31: Assistance mode GPS position in Curve 1 for participant B

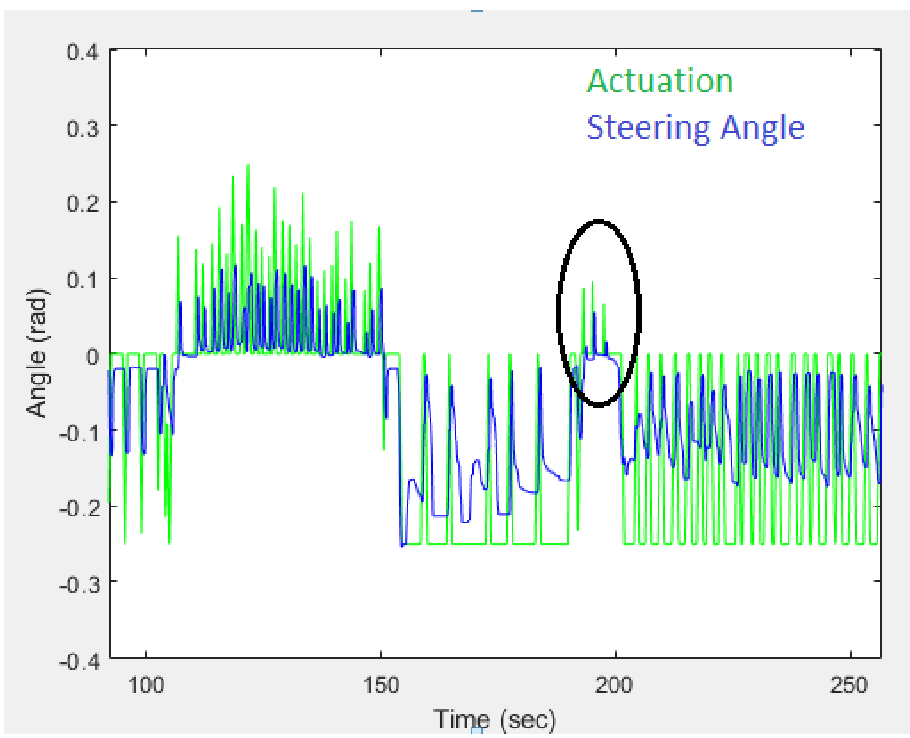


Figure 32: Assistance mode Actuation & Steering angle in Curve 1 for participant B

Figure 33 show the gaze fixation of the participant for the three laps in steering assistance mode with the deviation occurring in lap 3. At the instance of the failure of the system, the participant gaze was concentrated on the near path of the vehicle. This supports the fact that the participant was completely involved in the driving exercise and supervised the system well and intervened to correct the system when necessary.

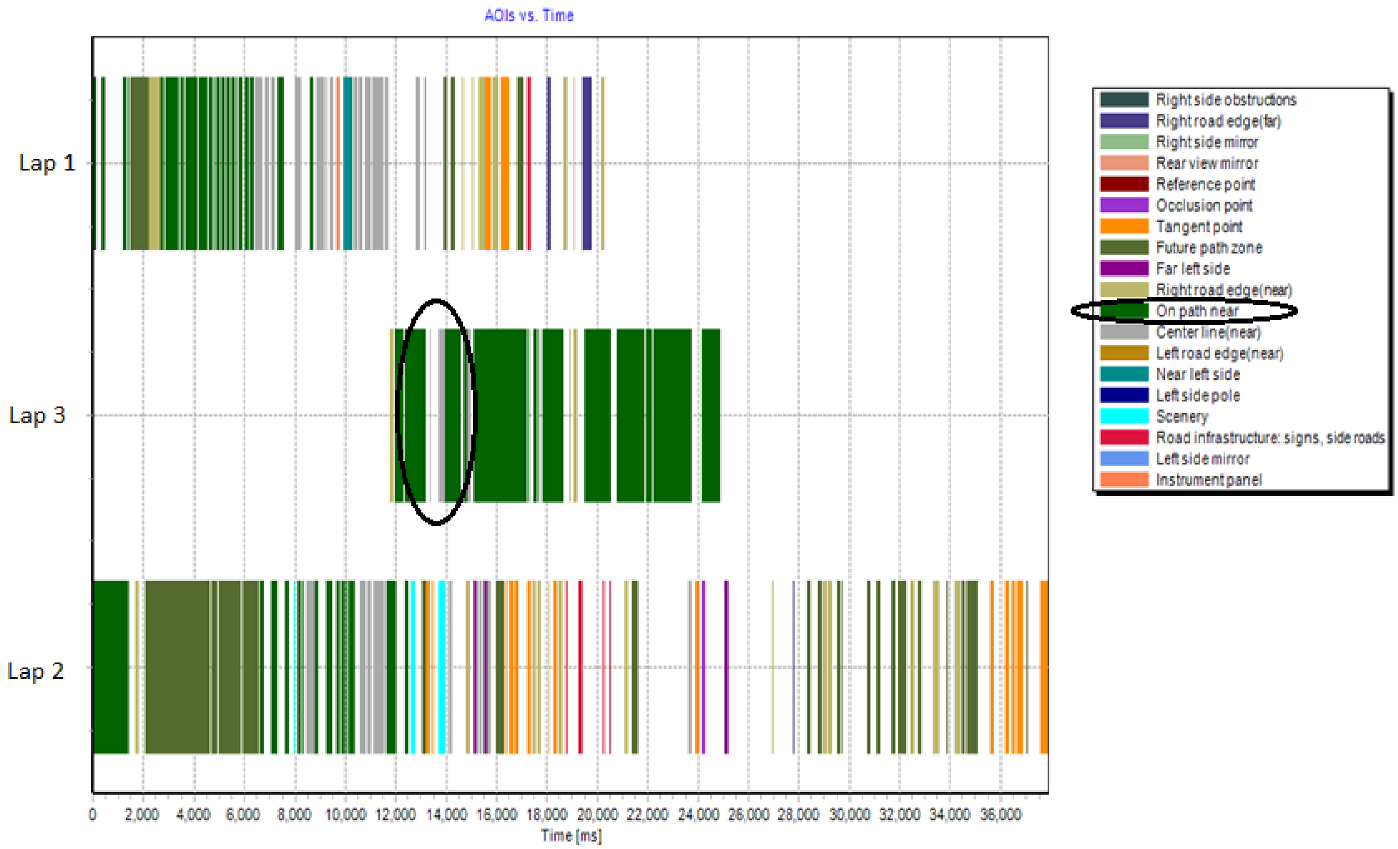


Figure 33: Fixation for participant B

Figure 34 show the level of trust the participants had on the steering assistance system. The trust scale was measured during the driving exercise after the completion of each lap in the steering assistance mode. The trust scale results shown below are the average trust values for each participant for three laps in steering assistance mode and the values vary between 0-20, with 0 meaning no trust and 20 meaning full trust. The level of trust on the system varied with some participants having high level of trust while the remaining having medium or low level of trust on the system. The investigated participants A and B have high and low level of trust on the system respectively. The level of trust that each of the drivers had on the system is reflective of the way they took control from automation, at times of system failure.

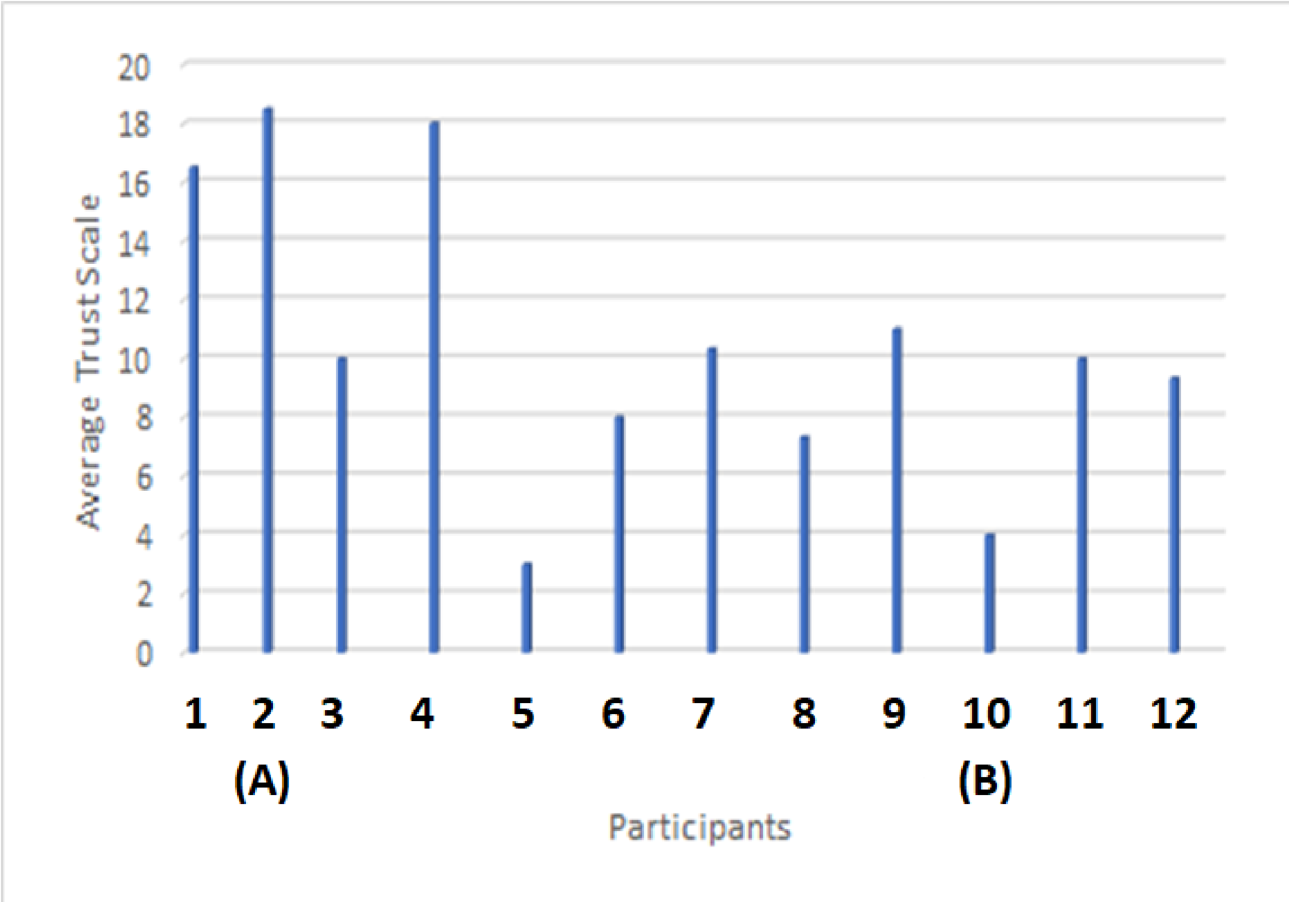


Figure 34: Trust scale

4 Discussion

In this study we record and analyze driver's gaze behavior along with the vehicle parameters while driving on a test track with steering assistance system. The study was done to investigate the driver's eye fixations during the system failure. Hence, the driver's gaze behaviour in both manual driving and steering assistance driving mode were recorded. There were some observations that were made from the analysis of the recorded data. The two participants analyzed interacted with the system on different levels. Participant A, didn't respond to the steering assistance system failures and had a high level of trust on the system. On the other hand, with low trust on the system, participant B made constant corrections to the system inputs and guided the vehicle on the correct path when the system failed. A general conclusion that can be made from this analysis is that participants with low level of trust on the system monitors and interacts with the system more compared to the participants with high trust.

For participant A, the actuation request and steering request have similar values for almost the entire duration of the lap. While for participant B, the actuation request and steering request are rarely similar. This means that the participant A allowed the vehicle to maneuver as per the joystick inputs from the experimenter. Whereas participant B was more focused on the driving task and dedicated his complete attention on road. This fact may again be substantiated with the level of trust on the system. As participant A had more trust on the system, maneuvering of the vehicle as per the joystick inputs were allowed. However, due to the low level of trust on the system, constant steering input corrections were made.

The gaze fixation results in manual mode showed that both participants were focused more on the road, as it involved complete control of the vehicle both longitudinally and laterally. The gaze patterns were scattered and at most instances of time the participants were looking at the road and occasionally towards the scenery. The eye tracking results discusses about only two participants as the eye-tracker data quality was good only for those participants. The eye-tracker was extremely sensitive to sunlight and gave distorted results on many occasions. This was one of the limitation of the study as there weren't many good quality participant data to analyze and arrive at a conclusion.

For the case of steering assistance system failure on curve 3 of the track on lap 2 for participant A, the gaze fixation results suggests that the participant was looking at the instrument panel for most parts of the failure and at the end started to look at the near left side. The in-vehicle camera showed that participant almost placed the hands on the steering wheel to gain control of the vehicle when the vehicle was completely out of lane, but retracted immediately and provided no steering inputs to pull the vehicle into the lane and didn't make an effort to correct the system. One of the possible reasons that the participant didn't respond to the failure was the fact that the participant was distracted which is evident from the eye-tracker results that show the gaze fixations were not on the road and were concentrated on the instrument panels. Another reason was due to the high trust on the system, the participant was waiting for the system to correct the path and get the vehicle back into the lane. However, for the remaining part of the lap after the failure, the gaze fixations were focused on the road.

For a similar case of steering assistance system failure on curve 1 of the track on lap 3 for participant B, it is seen that as soon as the vehicle starts to drifting off the lane, the participant pulls the vehicle back into the lane. The actuation and steering request plot of the participant for the particular scenario shows that, when an actuation to drive the vehicle off the lane is given and the participant corrects the steering angle input to the vehicle. The eye-tracker results suggests that the participant had the gaze fixed on the road completely and didn't look anywhere else.

To summarize, the two analyzed participants exhibited similar behaviour in manual driving, while having different behaviours in steering assistance mode under similar circumstances. The different strategies adopted by the participants could be owed to different level of trust on the system. One participant (Participant A) was attentive to the steering inputs and vehicle lane position and made correction for small deviations from lane. The participant had low level of trust on the system and hence was attentive on the performance of the system. The other participant (Participant B) did not respond to the lane deviations and trusted the system to make lane corrections. The participant had high level of trust on the system and hence was not keen on correcting the system.

4.1 Limitations

The main limitations for the present study are the following:

- Eye tracker was affected by glare due to sunlight and few laps had to be discarded and not fit for analysis. This reduced the data set to a fewer number. Also, the eye tracker had a horizontal and/or vertical shift in the eye positions from the actual position, even though it was calibrated after each lap for each participant.
- The joystick control used to drive the vehicle in steering assistance mode was too noisy. Also, the joystick was operated by a human. This could have had an impact on the way the participant trusted the system.
- Limited number of participants during the experiment and hence not good enough data set to make an overall conclusion.
- The experiment was conducted on the rural road on the AstaZero proving ground and hence does not account for city driving environment variables. Also, there was no oncoming traffic during the experiment. Presence of oncoming traffic could have changed the glance behaviour of the driver.

4.2 Future Scope

Since this experiment was a part of a course work, there was limited time to analyze deeper into the data. There is scope for more analysis on the collected data in order to establish any relationship between the drivers gaze behaviour and their ability to regain control when such a steering assistance system fails. By the use of a steering assistance software and use of a better eye tracker, it is possible to be able to collect more quality data that can be used for better analysis. There is scope to run this experiment in different road conditions such as city environment, highway driving, etc. This could give a larger scope of how drivers react in different scenarios.

References

[1] Skeete, J. (2018). Level 5 autonomy: The new face of disruption in road transport. Technological Forecasting and Social Change, 134, pp.22-34.

[2] Leicht, T., Chtourou, A. and Ben Youssef, K. (2018). Consumer innovativeness and intentioned autonomous car adoption. The Journal of High Technology Management Research, 29(1), pp.1-11.

[3] Inverse. (2019). Full Self-Driving Cars Could Arrive as Early as 2027 Thanks to This Chip. [online] Available at: https://www.inverse.com/article/49253-arm-unveils-self-driving-car-chip-to-enable-full- autonomy-by-2027 [Accessed 28 Jan. 2019].

[4] TechCrunch. (2019). BMW's self-driving car will aim for full Level 5 autonomy by 2021. [online] Available at: https://techcrunch.com/2017/03/16/bmws-self-driving-car-will-aim-for-full-level-5-autonomy-by-2021/?guccounter=1 [Accessed 28 Jan. 2019].

[5] Chalmers TU (2019). Research Infrastructure. [online] Available at:https://www.chalmers.se/en/researchinfrastructure/revere/Resources/Pages/Volvo-XC90.aspx [Accessed 28 Jan. 2019].

[6] Applanix.com. (2019). [online] Available at: https://www.applanix.com/downloads/products/specs/POS_LV_Datasheet_web.pdf [Accessed 28 Jan. 2019].

[7] Kapsch.net. (2019). [online] Available at: https://www.kapsch.net/ktc/downloads/datasheets/in-vehicle/5-9/KTC_DB_EVK-3300_17_web.pdf?lang=en-US [Accessed 28 Jan. 2019].

[8] Merat, N., Jamson, A., Lai, F., Daly, M. and Carsten, O. (2014). Transition to manual: Driver behaviour when resuming control from a highly automated vehicle. Transportation Research Part F: Traffic Psychology and Behaviour, 27, pp.274-282.

[9] Harbluk, J., Burns, P., Malone, D. and Hamilton, J. (2014). Power Steering Assist Failures. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 58(1), pp.2073-2077.

[10] Ren, Y., Li, X., Zheng, X., Li, Z. and Zhao, Q. (2015). Analysis of Drivers' Eye-Movement Characteristics When Driving around Curves. Discrete Dynamics in Nature and Society, 2015, pp.1-10.

[11] Forrest, C. (2019). The X-factor in our driverless future: V2V and V2I — ZDNet. [online] ZDNet. Available at: https://www.zdnet.com/article/the-x-factor-in-our-driverless-future-v2v-and-v2i/ [Accessed 28 Jan. 2019].

[12] Piccinini, G., Lehtonen, E., Forcolin, F., Engström, J., Albers, D., Markkula, G., Lodin, J., Sandin, J.How do drivers respond to silent automation failures? Driving simulator study and comparison of computational driver braking models

[13] Astazero.com. (2019). [online] Available at: http://www.astazero.com/wp-content/uploads/2016/09/Proving_ground_center.gif [Accessed 28 Jan. 2019].

[14] Chalmers TU (2019). Research Infrastructure. [online] Available at:https://www.chalmers.se/en/researchinfrastructure/revere/Resources/Pages/OpenDLV.aspx [Accessed 28 Jan. 2019].

[15] Size, F. and Wire, B. (2019). SMI Eye Tracking Glasses Set the Industry Standard for Professional Research and Training. [online] Businesswire.com. Available at: https://www.businesswire.com/news/home/20141219005468/en/SMI-Eye-Tracking-Glasses-Set -Industry-Standard [Accessed 28 Jan. 2019].

[16] Intelligence, G. (2019). Solutions for behavioral sudies, psychology and neuroscience research. [online] GAZE INTELLIGENCE. Available at: https://gazeintelligence.com/smi-product-manual [Accessed 28 Jan. 2019].

[17] Lappi, O., Rinkkala, P. and Pekkanen, J. (2017). Systematic Observation of an Expert Driver's Gaze Strategy—An On-Road Case Study. Frontiers in Psychology, 8.

[18] Continental-automotive.com. (2019). Continental Automotive. [online] Available at: https://www.continental-automotive.com/en-gl/Passenger-Cars/Chassis-Safety/Software-Functions/Cruising/Lane-Keeping-Assist [Accessed 28 Jan. 2019].

[19] Continental-automotive.com. (2019). Continental Automotive. [online] Available at: https://www.continental-automotive.com/en-gl/Passenger-Cars/Chassis-Safety/Advanced-Driver-Assistance-Systems/Driving-Functions/Lane-Departure-Warning [Accessed 28 Jan. 2019].

5 Appendix

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Participant information and consent form – Experiment at AstaZero

Background and purpose
This study is conducted to evaluate driver's behavior during driving in manual and steering assistance modes. This study is part of a student project performed at Chalmers University of Technology / SAFER under the supervision of Assistant Prof. Giulio Bianchi Piccinini and Post-Doctoral Researcher Esko Lehtonen.

What will happen in the study?
Your participation will take about 2-3 hours in total. You will be requested to drive an instrumented vehicle several times in the rural road test track at AstaZero, both in manual and steering assistance driving modes. Before starting the experiment, the test leader will explain you the detailed tasks that you have to carry out and you will be asked to perform a training ride session with the instrumented vehicle. During the training and during the experiment, data from the vehicle (speed, position, accelerations etc.), data about your driver eye location and video data of the external environment and your hands on the steering wheel will be recorded.

Possible risks
The risks associated to this experiment are the same that you would experience during regular driving on rural roads in Sweden. Besides, you need to be aware that, during driving in steering assistance mode, unexpected situations might occur at any time, due to limitations or failures of the system. For this reason, you should always keep your hands on the steering wheel and monitor the behavior of the steering assistance system. In case you feel uncomfortable during the experiment, please contact the experiment leader and the test will be stopped.

Data management and privacy
In addition to the data automatically recorded during driving (e.g. vehicle data, eye location, video data of the external environment and your hands on the steering wheel), we will ask you some personal information (e.g. age, driving experience, gender). For the processing of any data that can be referred to you as a person, we follow the General Data Protection Regulation (GDPR, Regulation (EU) 2016/679).

All the data that we collect with your help will be available to those who need data for their work in the current research project. We may publish conclusions based on statistical analysis of groups of participants. From these results, your identity cannot be recognized. All collected and unidentified raw data, i.e. unprocessed data from the driving experiment, will be stored by the project supervisors. You are entitled to access the data collected about you and your driving. To access the data, contact Esko Lehtonen (esko.lehtonen@chalmers.se) and Giulio Bianchi Piccinini (giulio.piccinini@chalmers.se) and tell them your Test ID. Since we store the data anonymously, we will not be able to identify your data with your name.

All information regarding the design, measurement equipment and results of the experiment is confidential. You may not, therefore, disclose any of this to any other person such as your colleague, family member or friend.

Your Test ID is: ________________

Voluntary participation and right to cancel
Your participation in the study is entirely voluntary. You are entitled to request that the drive be canceled at any time without specifying a reason. Canceling your participation will not adversely affect you.

Consent form

I have read and understood the information about the research study. I have had the opportunity to ask questions about what was unclear to me. I understand that I can cancel my participation to the study whenever I want without giving a reason.

I hereby consent to participate in the above research study.

□ Yes
□ No

I allow recordings, including video recordings or still images, to be published or displayed publicly in various contexts, such as in research reports, at conferences, or at training opportunities (not social media).

□ Yes
□ No

I allow the collected data, including video recordings or still images, to be reused in future research projects (e.g. master theses) by the research partners.

□ Yes
□ No

Would you like to be contacted again for participation in future studies?

□ Yes, my mail address is: ______________________________
□ No

Place: ______________________ Date: ______________________

Signature: ______________________________

Name in print: ______________________________

Figure 35: Consent form

Project "AEP-Steering Assistance" 2018-10-18 – 2018-10-24 SAFER

Test procedure

Preparation

- ☐ Consent Form
- ☐ Instruction
- ☐ Checklists

Meet and welcome TP

- ☐ Reminder of Toilet & Phone
- ☐ Explanation of the test procedure (roughly)
- ☐ Provide
  - Consent Form
  - Instruction
- ☐ Printing the AstaZero ID
- ☐ Clarifying of any questions

Explanation of the Test

- ☐ Safety instruction
  - Voice communication
  - Verbal communication about the speed limit

Start of Test

- ☐ Instructions regarding the test
- ☐ Go through the revere checklist
- ☐ Start the car and check programs
  - Close doors and check the eye tracker calibration.
  - Start the software.
  - Perform the joystick test
  - Check voice communication

Start of Trial

- ☐ Check if the data is being recorded
- ☐ Calibration of the eye tracker
- ☐ Check if the shoulder camera is recording
- ☐ Start the driving test
- ☐ Fill the work load questionnaire after each lap
- ☐ Break-
  - Switch the mode according to the set parameters
  - Clarifying of any questions

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Project "AEP-Steering Assistance" 2018-10-18 – 2018-10-24 SAFER

- ☐ Start the testing procedure all over again

Mark the test type(G,B or M) after each lap

Questionnaire & Debriefing

- ☐ Handing of the questionnaire and other related documents (allow answers in Swedish)
- ☐ Debriefing and open questions
- ☐ Cinema tickets

Page 2 of 2

Figure 36: Test procedure

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Detailed Instruction

Dear participant,

Thank you for participating in our study.

During the next hour, you will be driving this instrumented car in the rural road at AstaZero. The rural road has either one or two lanes.

We'll start with a short training for you to drive the car in manual mode, so that you can get familiar with it, by running maximum 2 laps. Afterwards, you'll have a maximum of 6 laps to drive in the steering assistance mode. In the steering assistance mode, the system will take over the longitudinal (e.g. accelerating and braking) and the lateral (e.g. steering) control of the vehicle. However, unexpected situations might occur at any time, due to limitations or failures of the system. In these situations, you can take over the longitudinal or lateral control of the vehicle by accelerating/braking or by steering the car. In case you need to regain full manual control of car, please press the emergency button 2 as soon as possible.

The drives in steering assistance mode will separated by a short break. During the break, we will recalibrate the eye tracker. After the calibration, you should not touch the eye tracker. In the end, we will ask you to fill out a short questionnaire.

Please don't hesitate to ask if you have any question.

Figure 37: Test Instructions

NAME: **DATE:** **TIME:**

CHECKLIST - II (Track Testing)

General CHECKLIST FOR REVERE VEHICLES (not specific to vehicle)

Out-Vehicle Check (to be filled by driver/passenger only)

- ☐ Physical tire state ok?
- ☐ Equipment fastened properly inside & on vehicle?
- ☐ Surrounding road environment free of nails, screws, tools, etc.?
- ☐ Valid driving license? Valid permit for driving at AZ?
- ☐ Valid test plan?
- ☐ Signed vehicle loan agreement?
- ☐ No loose tools, equipment, screws, etc. inside and on the vehicle?
- ☐ Educated about vehicle equipment?

In-Vehicle Check (to be filled by driver only)

- ☐ Seatbelts?
    - Check with passengers in vehicle
- ☐ Warning vests in vehicle?
    - Always wear a vest while working outside the vehicle during testing
- ☐ Comm. Radio in holder? Radio functional? (if applicable)
- ☐ No loose objects on vehicle dashboard (mobiles, etc.)
- ☐ Tested both emergency button performance?
- ☐ Educated about emergency assistance, contact for AZ, etc.?
- ☐ Educated about test plan?

Figure 38: Checklist for the participants

Participant ID: Lap Type:

The following questions refer to the workload on you using the system during the driving exercise:

1. How mentally demanding was the driving exercise? *

   Very Low — Very High

2. How Physically demanding was the driving exercise? *

   Very Low — Very High

3. How hurried or rushed was the pace of the driving exercise? *

   Very Low — Very High

4. How successful were you in accomplishing the task? *

   Perfect — Failure

5. How hard did you have to work to accomplish your level of performance? *

   Very Low — Very High

6. How insecure, discouraged, irritated, stressed or annoyed were you during the exercise

   Very Low — Very High

7. How much did you trust the steering assistance system during the driving exercise?

   Very Low — Very High

Figure 39: Trust Scale

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Drivers' visual strategies when a steering assistance system fails: A test-track experiment on AstaZero

*Required

To be filled by the test leader:

1. Name of the Participant*

    ____

2. Date*

    ____

3. Time (start of test) *

    ____

4. Participant ID*

    ____

5. Consent Form: Participation okay? *

    ◯ Yes

    ◯ No

    ◯ Other: ___________________________

6. Consent Form: Use of Data okay? *

    ◯ Yes

    ◯ No

    ◯ Other: ___________________________

7. Consent Form: Future use of Data okay? *

- Yes
- No
- Other: ______________________________

8. Consent Form: Contact for future participation okay? *

- Yes Email-ID: ______________________________
- No

To be filled by the participants:

9. Age in years*

____

10. Gender*

- Male
- Female
- Other
- Prefer not to disclose

11. Current Occupation*

____

12. When did you obtain your driving licence (year)? *

____

13. How many kilometres have you driven in your whole life (please estimate)? *

- ◯ < 3.000 km
- ◯ 3.000 – 10.000 km
- ◯ 10.000 – 30.000 km
- ◯ 30.000 – 100.000 km
- ◯ > 100.000 km

14. Which region of Europe/ World have you been driving the most? *

____

15. What kind of roads have you been driving the most? (Rural/ City/ Mountains/ Off-road/ Highway) *

____

16. What kind of car/ vehicle do you drive often? (Sedan/ SUV/ Estate/ Hatchback/ Minivan) *

____

17. Where do you think the eye remain focused during most time for an average driving? (Interior Vehicle/ exterior vehicle/ Road signs/ Road ahead) *

____

The following questions refer to your driving behaviour during last 12 months:

(You don't need to give exact numbers. This information helps us to get an impression on your driving experience.)

18. On average, how many times a week do you drive? *

    ____

19. Do you have any previous experience driving with the Steering assistance system? *

    ◯ Yes

    ◯ No

20. If yes, please describe shortly, how often and regularly you use/used this system. *

    ____

    ____

    ____

21. Would you use the Steering assistance system over Manual driving in future? *

    ◯ Yes

    ◯ No

22. Did you experience any system failures with Steering assistance system? *

    ◯ Yes

    ◯ No

23. If yes, please describe shortly what happened. *

    ____

    ____

    ____

24. What was the first thing that alarmed you that there is a failure? *

____

____

____

____

25. Do you have any comments or open questions?

____

____

____

____

Thank You for your participation!!!

Figure 40: Questionnaire