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Entorno virtual para diseñar y validar futuras interfaces a bordo para vehículos autónomos

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Resumen

Esta tesis presenta un nuevo entorno virtual para apoyar exploraciones avanzadas de interfaces de usuario y modalidades de interacción para sistemas de transporte futuros. El objetivo principal del trabajo es la definición de soluciones de Realidad Aumentada diseñadas para aumentar la confianza en los vehículos autónomos. La idea básica es proporcionar información a los pasajeros sobre la información disponible para los módulos de Inteligencia Artificial (AI) a bordo del automóvil, incluido el comportamiento de conducción del vehículo y su toma de decisiones. El trabajo incluye tres fases centrales que se centran en el desarrollo de software para el banco de pruebas, la definición de interfaces y experimentos relevantes y pruebas enfocadas con paneles que comprenden diferentes datos demográficos de los usuarios. El entorno de trabajo específico del banco de pruebas experimental se compone de: - GTA V como entorno de prueba debido a su escenario complejo y sus gráficos hiperrealistas. - Volante y pedales para una conducción activa. - DeepGTA como marco de autocontrol. - Tobii Eye Tracking como dispositivo de entrada para las intenciones de los usuarios. Las investigaciones específicas se centrarán en el diseño y la exploración de un conjunto de mecanismos alternativos de retroalimentación visual (adopción de visualizaciones de AR) para recopilar información sobre el medio ambiente circundante y la toma de decisiones de IA. El rendimiento de estos se evaluará con los usuarios reales con respecto a su capacidad para fomentar la confianza en el vehículo y en el nivel de comprensión de las señales proporcionadas. Además, los estudios complementarios adicionales se centrarán en la exploración de diferentes diseños para activar el traspaso de conducción, es decir, el control del vehículo de transferencia de AI a los conductores humanos, que es un problema central en las realizaciones actuales de vehículos autónomos.

Palabras clave: Coche Autónomo; Confianza; Realidad Aumentada; GTA V; Eye-tracking; Inteligencia artificial; conducción autónoma; futuro automóvil; sistemas autónomos; Self-driving; Volante;

Abstract

This thesis presents a novel synthetic environment for supporting advanced explorations of user interfaces and interaction modalities for future transport systems. The main goal of the work is the definition of novel interfaces solutions designed for increasing trust in self-driving vehicles. The basic idea is to provide insights to the passengers concerning the information available to the Artificial Intelligence (AI) modules on-board of the car, including the driving behaviour of the vehicle and its decision making.

Most of currently existing academic and industrial testbeds and vehicular simulators are designed to reproduce with high fidelity the ergonomic aspects associated with the driving experience. However, they have very low degrees of realism for what concerns the digital components of the various traffic scenarios. These includes the visuals of the driving simulator and the behaviours of both other vehicles on the road and pedestrians. High visual testbed fidelity becomes an important pre-requisite for supporting the design and evaluation of future on-board interfaces. An innovative experimental testbed based on the hyper-realistic video game GTA V, has been developed to satisfy this need. To showcase its experimental flexibility, a set of selected user studies, presenting novel self-driving interfaces and associated user experience results, are described. These explore the capabilities of inducing trust in autonomous vehicles and explore Heads-Up Displays (HUDs), Augmented Reality (ARs) and directional audio solutions.

The work includes three core phases focusing on the development of software for the testbed, the definition of relevant interfaces and experiments and focused testing with panels comprising different user demographics.

Specific investigations will focus on the design and exploration of a set of alternative visual feedback mechanisms (adopting AR visualizations) to gather information about the surrounding environment and AI decision making. The performances of these will be assessed with real users in respect of their capability to foster trust in the vehicle and on the level of understandability of the provided signals.

Moreover, additional accessory studies will focus on the exploration of different designs for triggering driving handover, i.e. the transfer vehicle control from AI to human drivers, which is a central problem in current embodiments of self-driving vehicles.

Keywords : Autonomous car; Trust; Augmented reality; GTA V; Eye tracking; Artificial intelligence; autonomous driving; future automobile; autonomous systems; Self driving;

Novel synthetic environment to design and validate future onboard interfaces for self-driving vehicles

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Glossary

- **AR:** Augmented Reality, overlays the reality with computer-generated images, providing a new layer of information.
- **SD:** Self-Driving, vehicle navigated by a computer (AI), without the intervention of a human.
- **AD:** Active Driving, vehicle navigated by a human.
- **AI:** Artificial Intelligence, computer systems capable of perform task requiring human intelligence.
- **HMI:** Human-Machine Interaction, field of study focused on designing computers compatible with humans and its interaction.
- **HUD:** Heads-up display, transparent display that gives feedback to the driver.
- **TOR:** Take over request, transition from self-driving to active driving, usually when the AV cannot handle the situation.
- **OSC:** Open Sound Control, protocol for communicating between devices that provides real time control of sound.

Chapter 1

Introduction

1.1 Manual Driving

The invention of the wheeled motor vehicle has been a considerable advance for humanity. This revolution begins in 1769, with the invention of an automobile, with its own steam engine, capable of transport humans. It would not be until 1806 when the combustion engine running on fuel gas, gave a resounding turn in the automotive industry.

Furthermore, this milestone led to the development of the modern petrol engine system in 1885. Which gained popularity one year after, the year of the modern automobile, event attributed to Karl Friedrich Benz with the Benz Patent-Motorwagen.

Finally, Car powered by electric engine was the last improvement achieved , slightly present in 20 century, which has been developed and acquired importance during 21st century, due to lack of petrol and importance of renewable energy for the future.

1.2 Autonomous Driving

First autonomous self-sufficient vehicles, have appeared in the 1980s thanks to Carnegie Mellon University's Navlab and ALV[12].

With Milestones such as Mercedes-Benz and Bundeswehr University Munich's Eureka Prometheus Project[2], has given a way to the new revolution in automotive industry, step towards an era of autonomous vehicles.

Levels of driving autonomy

The Society of Automotive Engineers have distinguished 5 different levels of autonomy for driverless cars depending on the human interaction[29]:

- **Level 0 No Automation:** Complete human interaction.
- **Level 1 Driver Assistance:** Assistance system for steering or acceleration/deceletarion.
- **Level 2 Partial Automation:** Assistance system for steering and acceleration/deceleration
- **Level 3 Conditional Automation:** Autonomous Driving expecting that the human driver will respond to a request of intervene
- **Level 4 High Automation:** Autonomous Driving even in the human driver does not respond to a request of intervene
- **Level 5 Full Automation:** Complete self-driving vehicle

Where are we now?

After the differentiation of these levels of autonomy, Needs to be clarified in what level of driving autonomy we are right now.

Most of the companies are in level three which the vehicle handles most dangerous situations on the road. For instance: Tesla, Volvo, BMW, Renault and so on ...

Some companies are developing level four, which implies the full self-driving automation capable of handling all critical situations. As for example Waymo [33] the company which is related to Alphabet.

1.2.1 Current State of the Art

Many advances are taking shape in the panorama of artificial intelligence for AVs, improving computational and machine learning techniques such as Deep Learning[15] which uses an artificial neural network that is composed of a number of hierarchical levels.

New patents have been registered in different companies to implement what is reflected in the current testbeds for AVs. As for example a windshield patented by Apple[6] which includes different sensors such as infrared or camera sensors in which perceiving the environment that surrounds us can give us an additional layer of information in augmented reality. This is an approach of what new car will integrate in the future, enabling us to increase the trust in AVs.

1.3 Purpose

The purpose is to create a novel synthetic environment for supporting advanced explorations of user interfaces and interaction modalities, finding out which changes the automotive industry needs to increase user confidence in autonomous cars by running user tests.

1.4 Barriers

There are different barriers to overcome in order to fully integrate autonomous cars in our lives:

Technical Barriers

Firstly, So as to analyse all the environment surrounded by an AV and perform decisions based on it, a high capacity of data processing is needed. Moreover, to measure correctly the different conditions, The AV has to incorporate precise sensors. Last but not least, Accurate and efficient algorithms are needed, so that AVs can make the most optimal decisions in the shortest possible time.

Moreover, a problem to solve in relation to the testbeds is the fact that are focused on hardware ergonomics[28], which is a problem since the driver is changing the role to passenger, this type of ergonomic should be less relevant than the graphic ergonomics which the passenger could receive information of the surroundings environment.

Human Barriers

The most crucial barrier to be solved is the human factor, the most complex machine which in the next few years will have to earn their trust in order to make way for the new era of AVs[13].

This means, build a bidirectional interface, making possible that the human can understand the car but as well that the car can understand the human changing its behaviour based on user's state.

1.5 Goal

The main goal of this thesis is to build a testbed in order to design and validate future on-board systems which will help to create a Human-Machine Interaction so each could be understood by the other one knowing their behaviour by giving anthropomorphic characteristics to self-driving vehicles.

1.6 Methods

In order to test user interfaces and interaction modalities, a novel synthetic environment has been created, setting up Scenarios with different interfaces, paths, and weather conditions. Questionnaires will help us to measure the trust between different participants during the experience, allowing testers to give feedback about the testbed.

With all these results, Interfaces that will help to increase confidence in autonomous cars can be discovered. Being able to integrate these on-board systems into future autonomous vehicles.

Chapter 2

Background

2.1 Can we trust in AVs?

Driven by the recent developments in autonomous driving, the automotive and transportation industry is undergoing the most rapid evolution in its history. Cars are expected to rapidly transition from mere transportation means into the next generation of media and service platforms. However, recent surveys suggest that a significant portion of the general population is not currently willing to use autonomous vehicles, or may not feel comfortable riding in them [31] [30]. Michelle Lewis et al. mentioned in their research studies in *the role of trust in HRI*[17],*"Notion of trust involves vulnerability in circumstances of risk and uncertainty"* These hypothetical findings have been confirmed in empirical studies where participants were exposed on a daily basis to current self-driving technology, e.g. [16]. From the early works on trust it is clear that an inappropriate level of trustin a system may lead to its disuse (underutilization) or misuse (over-reliance). With AI progressively taking over most of the driving tasks, it is of paramount importance for the passengers to understand and trust the decision-making of the on-board autonomous systems. In order to redefine and todeepen the currently existing relationship between passengers/drivers and their vehicles, novel interaction opportunities between humans and -board AI units need to be supported and facilitated.

On the other hand, technical problems as the accuracy of sensors or the performance of AVs and its algorithms, will be solved in the near future. Humans are much complex than robots, and sometimes they do not trust AIs, that is why a HRI should be improved in order to solve this delicate issue.

2.1.1 Basis of trust in HRI and AVs

An article published in the *Journal of Experimental Social Psychology* [34] revealed that AVs would operate more competently and users' confidence would increase proportionally to their anthropomorphic characteristics.

Beyond this psychological fact, another way to foster trust is by designing anadvanced on-board HMI that both conveys the capabilities of the system to its passengers and reveals the operations of the automation in a comprehensible way, in order to know their behaviour. Requirement according to J. H. Koo et al. [14] and Lee et al. [16]

A study carried out by Hancook et al. entitled *A meta-analysis of factors affecting trust in human-robot*[10] interaction concludes that *"The robot performance and attributes were the largest contributors to the development of trust in HRI"*, this refers to the characteristics of the car, as well as its performance when processing environmental data and reacting as quickly as possible to these conditions. These characteristics help us to clarify that they are influential when it comes to gaining the confidence of people for the new generation of autonomous cars.

2.2 Related Work

Now that has being clarified what should be improved about AVs in order to foster trust in its users, providing feedback and giving anthropomorphic characteristics, an outline of the related work has to be given.

2.2.1 Simulators

Since autonomous and semi-autonomous driving represent a discontinuity for the passengers' experience, it is important to identify suitable tools for designing and validating the next generation of on-board interfaces. The use of simulators has become in the last decade a de-facto standard for both academia and industry [35]. In the context of self-driving, simulators have been proposed for two typically distinct purposes: a) the definition and evaluation of self-driving algorithms and b) the design and validation of user interfaces. Most of the research efforts have been focusing on the first class of simulators, with solutions both piggybacking on existing tools (e.g. [24]) or completely built from the ground up (e.g. [8]). In particular, the use of hyper-realistic video games, like GTA V, has been proposed as a way to improve annotation for object detection algorithms while introducing a range of variation in the data samples [24]. At the same time, video games like GTA V have hyper-realistic graphics and include wide maps across different landscapes and complex behaviours for secondary characters including other vehicles and pedestrians. However, video games are typically closed systems designed with specific purposes different than research. In order to cope with the closeness of these systems, some novel approaches have been targeting open and fully controllable environments, as it is done in CARLA [8]. Concerning using simulators as tools for the assessment of UX, a set of systems have been targeting increased immersivity by means of Virtual Reality (VR) interfaces e.g. [32] and [18]. While this approach allows users to experience the vehicles with 6DOF, both the graphics and the realisms of supported systems are far from ideal. Furthermore, it is unclear whether there are differences between utilizing standard flat screens simulators or VR systems [32].

2.2.2 Ergonomics

In terms of resemblance to reality, we refer to testbeds with respect to autonomous cars, it is necessary to mention ergonomics, in which good designed for efficiency and comfort is pursued. We can distinguish two different types in testbeds:

Hardware Ergonomics

Most current testbeds are focused on this first aspect [**?**], as it results in a better user experience by having an environment more similar to reality such as a realistic steering wheel or a race seat with vibration capability. But this is a less relevant aspect when talking about AVs since the drivers move to another role in which there are no longer drivers, instead they became passengers of the vehicle where they receive information of the surroundings environment.

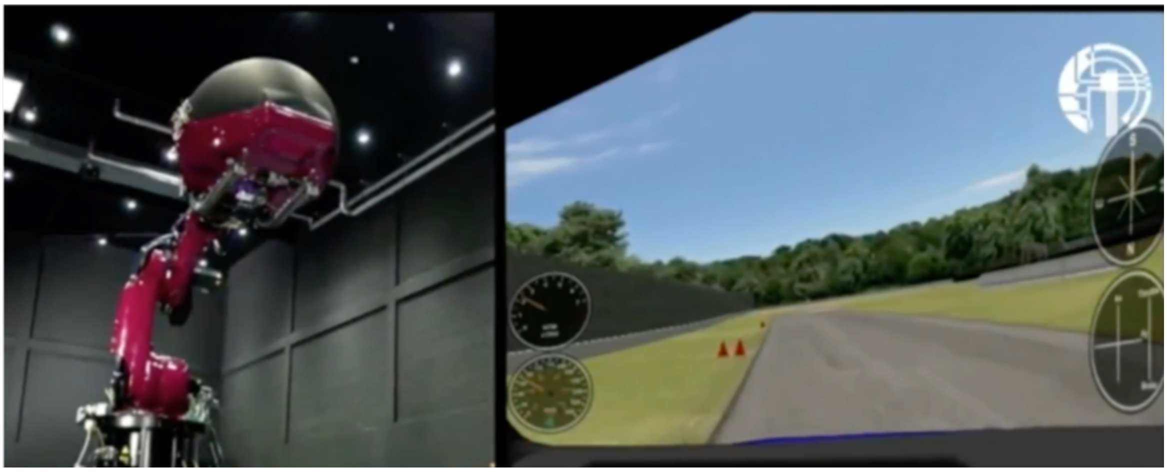

Fig. 2.1 Example of the ergonomics used in research for responses to take-over requests[28] for ACM CHI Conference 2018.

Graphic Ergonomics

This feature refers to having realistic graphics as are the scenarios of testbeds similar to reality such as GTAV[9] which has been used in this testbed. With a layer of augmented reality, giving feedback to the passenger of the movements and the processing of the objects that will make the AV, we can also improve this type of ergonomics in which the passenger can perceive a better experience thus increasing their confidence.

2.2.3 AR Interfaces

AR interfaces have been used in cars for different projects, for instance, to experiment with attentive user interfaces in order to evaluate and develop on-board AR interfaces[19]. The advantage of an AR layer is the fact that overlaying the reality directly, the system can show more information to the user giving extra feedback about the environment. Another more limited example is the HUD, due to it cannot augment all the reality of the environment but it is limited to a display in a part of the windscreen of the car[7]. Researches about AR systems that are designed to help guide the attention of drivers in dangerous situations, have revealed that the system is reliable and did not distract the users on-board[27].

Chapter 3

Description of the Novel Synthetic Environment

The specific working environment of the experimental testbed is based on GTA V due to its complex scenario and its hyper-realistic graphics. Which has gained popularity in recent years when creating research environments related to AVs. For instance, OpenAI[20]. a non-profit artificial intelligence research company chaired by Elon Musk, announced that was working on an open-source artificial intelligence project with GTA V.

3.1 Frameworks

3.1.1 Self-Driving Framework

In order to integrate other mods in GTA V, ScriptHook[5] is needed. This library allows the use of script native functions in .asi plugins, extension which the mods are based on. DeepGTAV[25] is an open source framework that transforms GTAV in a research environment related with AVs. This library is used to access all objects of GTA's environment[4] being able to configure them. Moreover, deals with line rewarders in order to perform self-driving actions. The problem with DeepGTAV is that it is attached to the game and it is difficult to configure with different environment parameters during the experiment. So as to facilitate this process, VPilot[26] has been developed, a client written in Python that establishing a TCP connection allows an easy set-up of the testing environment, being able to configure the different test scenarios with a wide range of possibilities.

3.2 Implementation

3.2.1 HUD

A research environment with a HUD has been integrated in order to measure the trust in self-driving cars, this display allow users to see AVs behaviour and information related to the environment. For example, Indicating in advance, the direction which the car is heading, with the help of an arrow.

This information is limited to the display screen, that is, an augmented reality layer will not be available and we cannot see additional information about the car beyond the HUD.

Fig. 3.1 Example of HUD. The information is spatially limited in the projecting dark area at the center-bottom of the screen. Downtown configuration during the night with rainy weather

3.2.2 ARLayer and Eye Tracking

Another approach to present information about the environment is to create an AR layer, simulating that a vehicle's windscreen can show additional information that the car is perceiving. For instance, highlight the cars in order to show a warning situation, so as to users can see that the AV is aware about a danger situation, and will take action in this regard.

Helping us from Tobii eye tracker 4c, more feedback to the user can be provided, highlighting the cars and pedestrians in a specific area where the user is looking at, as well as showing alerts that follow our gaze so that we do not go them unnoticed.

Fig. 3.2 ARLayer example. Downtown Environment configuration with sunny weather. Highlighting pedestrians via Eye-Tracking

3.2.3 Steering wheel and Vertical Handover

In order to compare AVs with Active driving, a steering wheel is needed. In this experiment a Logitech G920 Driving Force has been used, supporting force feedback. To test subjects' feeling of a real car, it is important to be able to control the vehicle motion via steering wheel and pedals when in "active driving" mode and to see the correct steering wheel movements when in "self-driving" mode. In order to do so, the "Manual transmission" mod from "ikt" has been modified[11] to receive driving information from DeepGTAV and control input to VPilot.

This steering wheel has also been used to compare between the transition from self-driving to active driving during dangerous situations where the user has to take control of the car, Because it cannot address the situation by itself.

3.2.4 Shocking Events and Event Manager

In order to analyse dangerous situations on the road with AVs, shocking events have been created in specific points of the experiment, some consist of a car accident and the other that a pedestrian crosses the road without realizing that the traffic light is in Red.

These events have been tested first by not giving feedback to the user, On the other hand, with an event manager in which feedback is provided to the user that the car has detected a dangerous situation and can take charge of it, by braking and avoiding the collision.

Fig. 3.3 This image shows a pedestrian shocking event, the car detects that a pedestrian is crossing in red and automatically reacts triggering the brakes.

3.2.5 Audio Feedback

With the purpose of increasing the information that AVs provide to the user, fostering their trust, a sound feedback has been implemented for different situations.

Using Open Sound Control, a protocol for communicating between devices that provides real time control of sound with a flexible and intuitive interface. Using a UDP connection in which datagrams can be sent quickly and safely to their destination.

Here is a description of the feedback sound implemented:

- Cars near to crash: playing a beep when a car is approaching to the AV sensors, the greater the proximity to the other car the more rapid the beeping is.
- Vertical handover: When a situation is not approachable by the AV, the vertical handover is triggered, but sometimes it cannot be addressed. Therefore, audio feedback is notifying to the user of AV actions and also a countdown is played so that the user know at what exact moment the control of the car must be taken.

- Event manager: When dangerous situations occur on the road and the AV takes care of them, the environment has been set to reproduce a sound, warning the user that the car has perceived that situation and will take measures to resolve it.

3.2.6 Environment Conditions and Driving Setting

Different environments have been configured using VPilot to test user in different realistic situations, for instance, change the traffic, weather condition as well as the driving style of the AVs and its speed.

Here is an example of the Scenario configured for one test case:

```
Scenario(drivingMode=[lastDrivingMode, lastSpeedHighway], weather=lastWeather,
 vehicle='Blista', time=[lastTime, 00], startingPoint=[106.23, -1277.571, 28.9, 10
 location=[2547.274414, 341.763397], shockingEvents=True, ARLayer=ARLayer,
 EyeTracking=ARLayer, EventManager=True, HighlightCarToCrash=HighlightCarToCrash,
 HUDLayer=not ARLayer, VerticalHandover=False, AxisCam=[0, 1, 0.8, 60],
 SpeedVector=SpeedVector, XRESOLUTION=XRESOLUTION, YRESOLUTION=YRESOLUTION)
```

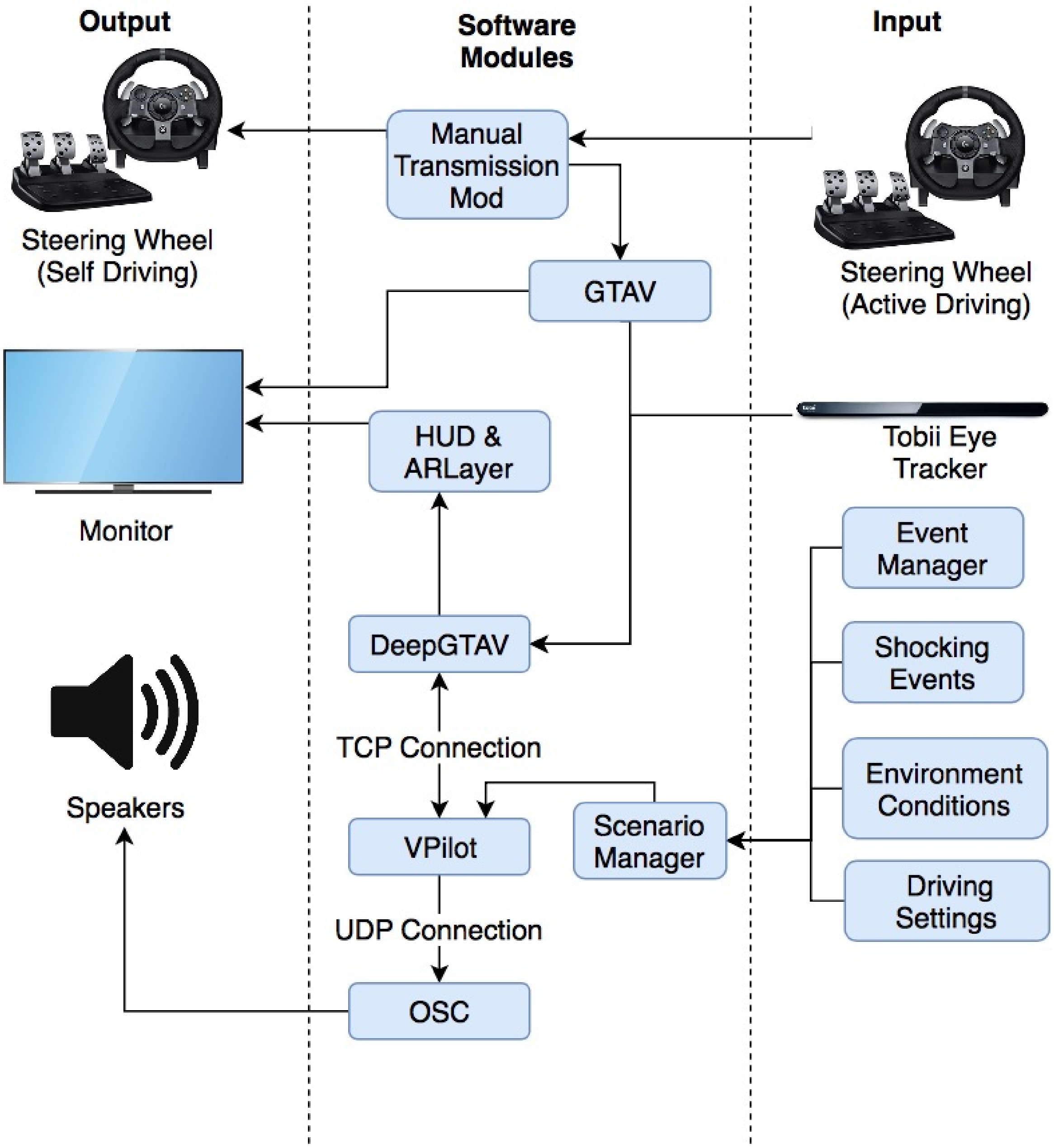

Fig. 3.4 Description of all the components that make up the test environment

Chapter 4

Methods

4.1 Experiment Design and its procedure

The design of the experiment, as shown in figure 4.1 consist in different parts taking around 30 minutes per each participant. Firstly, there is an explanation about the purpose that the thesis wants to achieve and about the different interfaces an images that the user is about to see. After this, there is a calibration of the eye tracker in order to see if the accuracy is properly configured. Once done with the calibration, participants are asked to fill out a test about driving experience, demographics and basic information about themselves.

The user now is ready to test the simulator. So as to compare the feedback that gives the interface to the user compared with the lack of one, in each experience, at first a non-feedback test is done which gives a way to the interface experiment with feedback. At the end of each experience there is a test of the interface that the user has just tried. Finally when all of them are done there is a last form where the user can give feedback about the testbed and the experiment in order to improve it and see further studies.

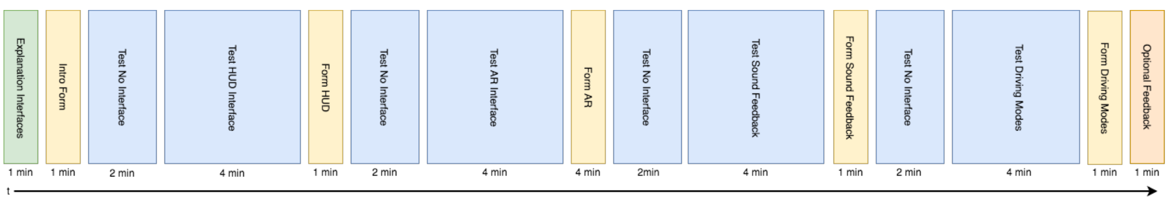

Fig. 4.1 Description of the experiment timing

4.2 Scenarios

For the testbed, 4 different types of configurations with 4 scenarios in each were chosen, combining different weather conditions (rainy and sunny), paths (Highway and Downtown), times of the day, each one with distinct interfaces. Beginning with the HUD interface followed by AR Interface, Sound Feedback and Driving Modes. In each Scenario there are pre-configured starting and ending point so the same path can be reproduced for the non-feedback and the feedback part. In the first part with no interface a shorter path has been chosen in order to streamline the process.

The 2 different types can be distinguished in the images below

Type 1 HUD	Highway & Sunny	Downtown & Rainy	Highway & Sunny	Downtown & Sunny
Type 2 AR	Downtown & Sunny	Highway & Sunny	Downtown & Rainy	Highway & Rainy
Type 3 Sound Feedback	AR Highway & Rainy	HUD Downtown & Rainy	AR Highway & Sunny	HUD Downtown & Sunny
Type 4 Driving Modes	HUD Downtown & Sunny	AR Highway & Sunny	HUD Downtown & Rainy	AR Highway & Rainy

Fig. 4.2 Description of all different possible Scenarios

4.3 Questions

A battery of multichoice questions has been made, about General information and basic driving skills. Moreover to collect data from each interface that has been implemented. For more detailed information here is the Google form used for collecting user experience feedback [3]. The results can be found in the **Appendix A**.

4.4 Testers

Seventeen testers, with ages in the range 21-65, have been recruited for this initial testing campaign. Each of them was exposed to the four different aforementioned interfaces.

Chapter 5

Results

In order to measure the impact of the testbed in participants' trust about AVs, guidelines has been followed with the book of Interaction design by Preece et al. [23]

A set of questions has been made in the questionnaire to collect the data of the testers so as to analyse the results and have conclusions about it. This questionnaire has been made for 17 participants, therefore, the data will be analysed from these results, but different conclusions may have been drawn with a different number of testers.

5.1 Comparing interfaces by average score

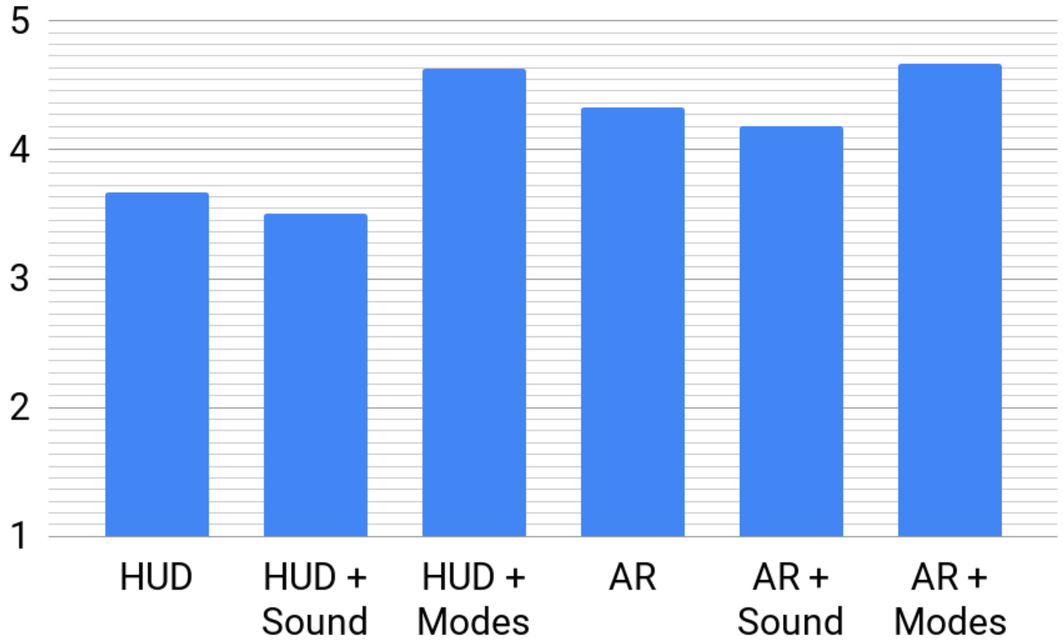

Fig. 5.1 Average value of each interface. The values are on a five-point likert scale from 1: Decreased my trust a lot to 5: Increased my trust a lot.

Every interface with an AR layer has had more positive impact in testers' trust, more than the HUD. We think that is because the HUD is limited to a small display and cannot provide a full augmented reality information experience. The average is one point greater in each type of interface (Normal AR Layer, with sound or with Driving Modes). The transition from a basic HUD or AR layer interface to one with sound has decreased the confidence of the users, we believe that this is due to the fact that many factors are taken into account by the car, so there is too much information about the environment. On the contrary, when the user was able to change the driving styles, the confidence of the users increase, because the user perceives that he has more control over driving modes of the AV, which can be changed programmatically by pressing a button in the testbed.

5.2 Comparing interfaces by different dimensions

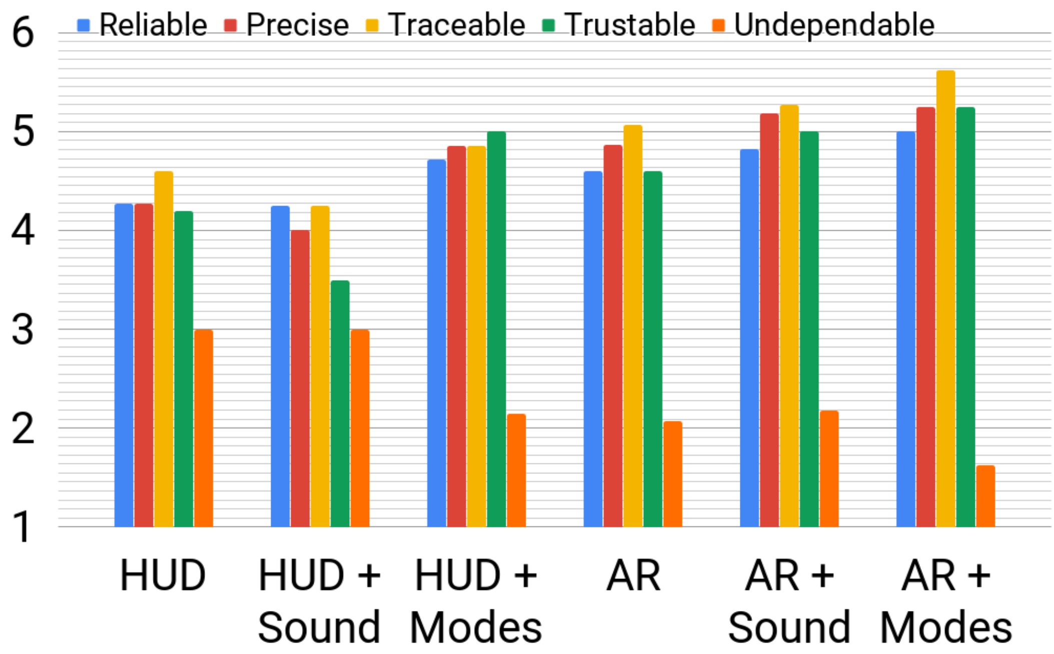

Fig. 5.2 Average value of the different components of trust, i.e. statements that the system is Reliable, Precise, Traceable, Trustable and Undependable. The values are on a six-point likert scale with 1: completely disagree, 2: largely disagree, 3: slightly disagree, 4: slightly agree, 5: largely agree, 6: completely agree.

The results concerning the impact of the considered interfaces on trust in self-driving cars is shown in Fig 5.2. There, the average score of a questionnaire exploring user agreement in respect to a set of characteristic of each interface are analysed. The considered dimensions are represented by the adjectives Reliable, Precise, Traceable, Trustable and Undependable. The results show that, as expected, AR scores significantly higher than HUD. However, when a basic HUD is complemented by the possibility of control- ling the self-driving behaviour (“aggressivity" and speed) the gap in performances is essentially eliminated. A similar increase is also shown when adding the control of driving modes to the AR interface. In this case the system becomes extremely traceable, allowing users to clearly understand the decision making of the on-board AI. The impact of sound on performances is definitely interesting. When it is added to the HUD interface, the performances are slightly deteriorated. We suspect that this is due to the limited space of the display, which does not convey enough information on what is causing some of the sound alarms. On the contrary, when sound is adopted as complement for the AR interface, essentially all performances are improved.

While these results are promising, they represent an initial exploration with simplified embodiments of the proposed interfaces. The exploration of directional sound sources matching the direction of registered obstacles is an interesting area for future development.

5.3 Comparing interfaces with decoupled results

	Sunny	**Rainy**	**Highway**	**Downtown**
HUD	4,11	4,375	4,33	4,13
AR	4,88	4,44	4,5	4,77

Table 5.1 Results of scenario configurations decoupled in order to be independent from each other

The results obtained in the different configurations of the scenarios (Sunny, Rainy, Highway and Downtown with HUD or AR Layer) has been decoupled in table 5.1 in order to be independent from others, in a scale from 0 to 6. It can be appreciated more clearly that the configuration with less impact in trust for users is the HUD in a sunny environment followed by the Downtown configuration in HUD, when more information is needed due to the clarity an the amount of traffic in this situation.

On the other hand, the best result obtained in this approach is a sunny configuration with an AR layer in which the objects can be recognized easier than in a rainy environment. This is followed by a Downtown configuration in a AR layer, related with the fact that in this environment there are more cars rather than in the highway, where less information can be provided.

5.4 Relation between driving skills with HUD/AR

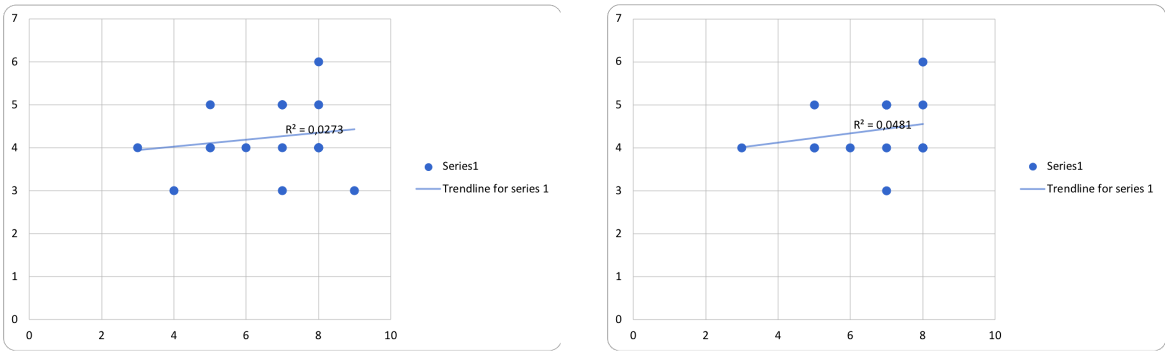

Fig. 5.3 Driving Skills and HUD

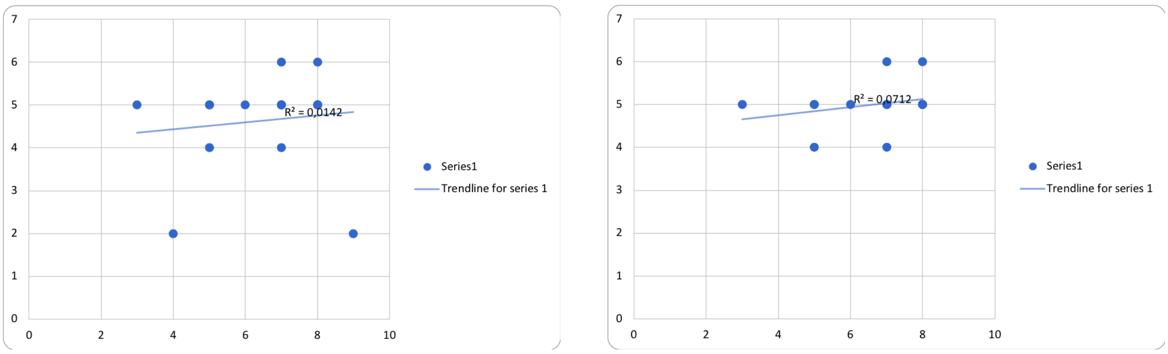

Fig. 5.4 Driving Skills and AR

In the 4 figures above it can be appreciated the relation between driving skills (X axis) with the level of trust obtained from HUD/AR in the user tests (Y Axis) through linear interpolation. The figures on the left represent all the results obtained from the different interfaces whereas in the ones on the right 2 outliners has been removed in order to see if there was some better interpolation in which the data had a better correlation.

But even removing the 2 outliers that could produce noise to the results obtained, values do not fit good at all, we think that is because the number of data collected is not large enough to draw conclusions sufficiently accurate.

5.5 Relation between deaths by country per year and driving skills

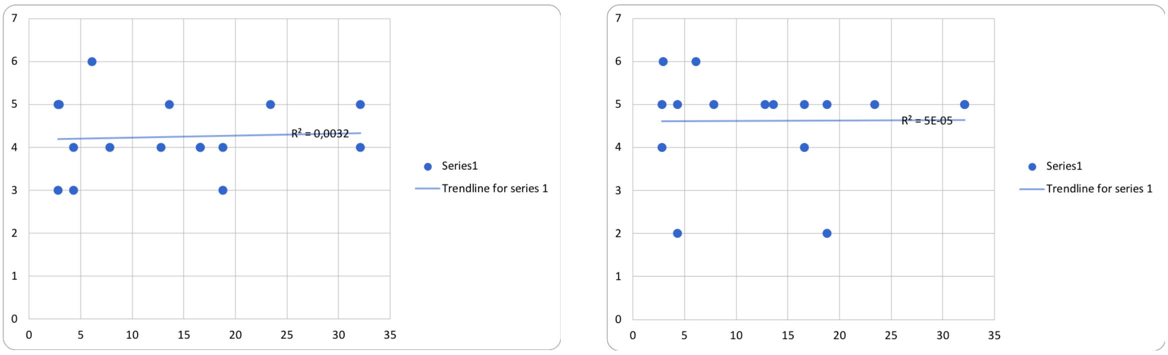

Fig. 5.5 Relation between deaths by country per year and driving experience

Here in these two charts above it has been represented the relation between the driving experience (Y axis) obtained in HUD (figure on the left) and AR (figure on the right) from users with different demographics with the deaths by country[1](X axis) in each case through linear interpolation.

It cannot be appreciate relevant data in any of the two figures, there is an strange behaviour in which the correlation cannot be appreciated. We believe that this could be for the same reason as the other figures mentioned above, which lacked a sufficient number of data to draw clear conclusions.

Chapter 6

Conclusions

This thesis is focused on developing a novel synthetic environment for supporting advanced explorations of user interfaces for future transport systems. With the help of Augmented Reality solutions combined with Artificial intelligence modules, the trust in passengers of AVs would increase as soon as we attribute anthropomorphic characteristics to this type of vehicles. Showing the intentions that the AV is processing in that moment and providing an additional layer of information about the objects that surround passengers. This testbed is developed to solve the realism problems that the current industrial testbeds have. Most of these are focus on the ergonomic aspects but give less importance to the realism of the scenarios which are not similar to reality. Based on the hyper-realistic video game GTA V this aspect has been solved by improving the visual components of the scenario as well as the behaviour of other cars on the road and pedestrians. This feature will facilitate the creation of new interfaces exploring Heads-Up Displays (HUDs), Augmented Reality (ARs) and directional audio solutions.

Different types of interfaces have been developed in the testbed, there are six: HUD, AR, HUD + Sound Feedback, AR + Sound Feedback, HUD + Driving Modes and AR + Driving Modes. The AR configuration caused a improved the trust more than the HUD, since the latter is limited to a small portion of the windscreen and does not place information in space where it is relevant, on the contrary the AR layer occupies all the possible space of this being able to show more useful information to the passenger augmenting the information and the perception of the objects that surround us. The sound interface has slightly decreased the trust of the users, we believe that this is due to the fact that many factors are taken into account by the car and the sounds sometimes can be overwhelming. Moreover, similarly with HUDs, the sound alert does not specify spatially the position of the obstacles that the alert refers to. Oppositely, when the user was able to change the driving styles, the confidence of the users increased, because users perceive that they have more control over driving modes of the AV, which can be changed programmatically in the testbed.

This simulator will help to improve the bidirectional relationship that there must be between autonomous cars and their passengers by providing new on-board interfaces, thus increasing confidence in users, giving way to an era of autonomous driving.

To summarize:

- Testbeds should focus on Graphic Ergonomics (realistic)
- AR Layer slightly better results than HUD
- Sound feedback slightly decreasing trust
- Driving modes increasing trust
- Testbed to validate future on-board systems

6.1 Further Studies

A possible future work to extend the functionality of this thesis would be to add support of biosensors in order to change programmatically the behaviour of the vehicle, for instance if the heartrate is increasing a software module could detect it and take actions on the behaviour of the car, slowing down or changing the driving mode of the AV. This would consolidate a better human-machine interaction.

Another possibility could be recreate a realistic environment in GTAV to control remote busses for public transport over 5G and model the communication systems characteristics, for example controlling the latency between remote vehicles, as well as controlling the location of the current bus. In 6.1 a first approach of this environment, implemented for Drive Sweden event, can be appreciated.

This testbed has been prepared for handover studies with audio feedback, but since it has been a broad field of study, experimental investigations have not been carried out.

Another option would be to integrate the testbed with some more advanced motion planning and self-driving algorithms that are not exclusively vision based, as in this case. We could also model LIDAR and radar sensors and use these models to filter the full information available from the game engine.

Last but not least, the exploration of directional sound sources matching the direction of registered obstacles is an interesting area that would improve the feedback given to the passengers.

Fig. 6.1 Approach implemented for Drive Sweden Event at KTH

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Appendix A

Form Questions

Date	Experiment Type:	driving experience	gender	age	country you acquired experience	rate your driving skills
2018/06/08	Type 1	0 - 3 years	Male	22	Portugal	8
2018/06/11	Type 3	3 - 5 years	Male	22	Italy	8
2018/06/11	Type 4	5 - 10 years	Female	26	Germanz	9
2018/06/16	Type 4	0 - 3 years	Male	21	UK	7
2018/06/16	Type 1	0 - 3 years	Male	24	China	3
2018/06/16	Type 2	No experience	Female	26	none	5
2018/06/19	Type 3	5 - 10 years	Male	23	Germany	8
2018/06/20	Type 3	10+ years	Male	30	Brazil	8
2018/07/02	Type 3	3 - 5 years	Female	25	India	7
2018/07/02	Type 2	0 - 3 years	Male	22	India	5
2018/07/02	Type 2	10+ years	Male	60	Sweden	7
2018/07/02	Type 1	3 - 5 years	Male	30	Bangladesh	5
2018/07/02	Type 4	10+ years	Male	57	Sweden	7
2018/07/02	Type 3	5 - 10 years	Male	27	Iran	6
2018/07/02	Type 3	0 - 3 years	Male	31	China	4
2018/07/03	Type 2	10+ years	Male	32	Egypt	8
2018/07/03	Type 2	3 - 5 years	Male	26	Iran	7

A.1 HUD

Scenario shown	How the interface change your trust in the system? (compared with no interface)
Highway Rainy	3
Highway Sunny	4
Downtown Sunny	4
Downtown Sunny	4
Highway Rainy	4
Downtown Rainy	3
Highway Sunny	3
Highway Sunny	3
Highway Sunny	3
Downtown Rainy	4
Downtown Rainy	4
Highway Rainy	4
Downtown Sunny	4
Highway Sunny	4
Highway Sunny	4
Downtown Rainy	3
Downtown Rainy	4

The self-driving system is reliable	The self-driving system is precise
5	5
6	6
3	2
5	5
5	4
4	4
4	4
5	5
4	4
4	4
5	6
3	3
5	2
4	5
2	5
4	5
4	5

The self-driving system easy to understand the actions it is taking	self-driving system is trustable
6	4
6	6
6	3
6	5
5	4
4	4
5	4
4	5
4	4
5	4
4	5
4	5
2	3
3	4
5	3
4	4
4	5

I cannot depend on the self-driving system
2
2
5
2
4
3
3
1
3
4
2
3
4
2
5
3
2

A.2 AR

Scenario shown	How the interface change your trust in the system? (compared with no interface)
Downtown Sunny	5
Downtown Rainy	5
Highway Rainy	4
Highway Rainy	5
Downtown Sunny	4
Highway Sunny	4
Downtown Rainy	4
Downtown Rainy	4
Downtown Rainy	4
Highway Sunny	4
Highway Sunny	4
Downtown Sunny	5
Highway Rainy	5
Downtown Rainy	4
Downtown Rainy	4
Highway Sunny	4
Highway Sunny	5

The self-driving system is reliable	The self-driving system is precise
5	5
6	6
2	5
6	6
5	4
5	5
5	4
5	5
4	4
4	4
5	6
6	5
5	5
4	4
2	5
5	5
5	5

The self-driving system easy to understand the actions it is taking	self-driving system is trustable
6	5
6	6
5	2
6	6
5	5
5	5
5	5
5	5
5	5
5	4
5	5
6	5
2	4
5	5
5	2
5	5
5	5

I cannot depend on the self-driving system

2
1
2
1
2
2
2
1
2
3
1
2
4
2
4
2
2

A.3 Sound Feedback

Scenario shown	Which interface was used?
Highway Rainy	AR
Highway Sunny	AR
Downtown Sunny	HUD
Downtown Sunny	AR
Highway Rainy	AR
Highway Sunny	AR
Highway Sunny	AR
Highway Sunny	AR
Highway Sunny	AR
Downtown Rainy	HUD
Downtown Rainy	HUD
Highway Rainy	AR
Downtown Sunny	HUD
Highway Sunny	AR
Highway Sunny	AR
Downtown Rainy	HUD
Downtown Rainy	HUD

How sound change your trust in the system? (compared to only visual implementation - no sound)

5
5
1
4
4
3
4
4
4
5
4
5
4
4
4
4
4

The self-driving system is reliable

5
6
5
6
5
5
5
5
5
3
5
5
4
4
2
5
5

The self-driving system is precise	The self-driving system is traceable (Its easy to understand)
6	6
6	6
5	5
5	6
4	5
5	5
6	4
5	5
5	5
3	5
6	5
5	6
2	2
5	5
5	5
5	5
5	5

The self-driving system is trustable	I cannot depend on the self-driving system
5	2
6	1
2	3
6	2
5	2
5	2
5	2
5	1
5	3
3	4
6	1
5	2
3	4
5	2
3	5
4	2
4	2

A.4 Driving Modes

Scenario shown	Which interface was used?
Downtown Sunny	HUD
Downtown Rainy	HUD
Highway Rainy	AR
Highway Rainy	AR
Downtown Sunny	HUD
Highway Sunny	AR
Downtown Rainy	HUD
Downtown Rainy	HUD
Downtown Rainy	HUD
Highway Sunny	AR
Highway Sunny	AR
Downtown Sunny	HUD
Highway Rainy	AR
Highway Rainy	AR
Downtown Rainy	HUD
Highway Sunny	AR
Highway Sunny	AR

How did being able to change driving modes change your trust in the system?

4
5
4
5
5
5
4
5
5
5
5
5
5
3
4
5
5

The self-driving system is reliable

4
6
5
5
6
6
5
6
5
5
5
5
3
4
3
5
6

The self-driving system is precise	The self-driving system is traceable (easy to understand)
5	6
6	6
5	4
5	6
6	6
6	6
5	6
5	5
5	5
5	5
6	6
5	6
2	2
5	5
5	5
5	5
5	6

The self-driving system is trustable	I cannot depend on the self-driving system
4	2
6	1
5	2
5	1
6	1
6	1
5	2
6	1
5	2
5	3
6	2
6	1
3	4
5	2
4	3
5	2
5	1