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INTELLIGENT FUNCTIONS DEVELOPMENT ON AUTONOMOUS ELECTRIC VEHICLE PLATFORM

Autonomous driving is no longer just an idea of technology vision instead a real technical trend all over the world. The continuing development to a further level of autonomy requires more on mobile robots safety while bringing more challenges to human-vehicle interaction. A robot autonomous vehicle (AV) as a research platform operates an experimental study on human-AV-interaction (HAVI) and performs a novel method for mobile robot safety assurance. Not only autonomous driving technology itself but human cognition also performs an essential role in how to ensure better autonomous mobile robot safety. A Wizard-of-Oz experiment in the university combing a survey-based study indicates public attitudes towards driverless robot vehicles. HAVI experiment have been carried through light patterns designed for experiment. This paper presents an attempt to investigate humans' acceptance and emotions as well as a validation to bring the mobile robot vehicle to a high-level autonomy.

1. INTRODUCTION

As more improvement coming from every aspects of technology, the greatest barrier standing in the way of the advent of fully autonomous robot vehicles lies in building people's trust in the machine and enhancing their sense of safety. Companies and researchers are trying hard to cut down the cost which makes the question no longer is if it's possible to enable autonomous vehicles, it's down to, will we allow this foreseeable future to happen. A team from Stanford found that, for AV, most humans managed to make crossing decisions based on vehicle cues alone instead of communicating via driver cues [1]. Master students from Chalmers University [2] raised the opinion that vehicle movement alone is not enough to compensate for the loss of driver cues in AVs and the creation of specialized interfaces for communicating with humans is needed. Scholars in US [3] investigated intent communication cues for AVs by comparing the effectiveness of various methods of presenting human-vehicle

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street crossing information. All the investigations above have consolidated the necessity of Human-Autonomous Vehicle-Interaction research. The main aim of the paper is to give an overview on current state of the art on the topic of robot human-autonomous vehicle interaction (HAVI). A Wizard of Oz [4] experiment is a research experiment in which subjects interact with a computer system that subjects believe to be autonomous has been done during performed studies. The results of experiment are analysed and discussed.

According to ERTRAC (European Road Transport Research Advisory Council) [5], the following chapters (Fig. 1) list the main challenges and objectives on the path to higher levels of automation. To this, policy and societal aspects must be firstly addressed to ensure proper user information and acceptance, then it will trigger the necessary regulatory adaptations.

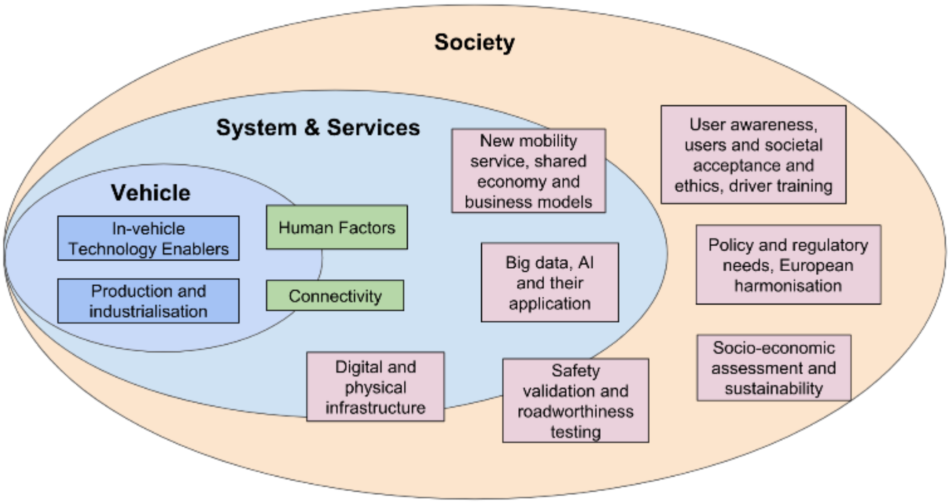


Fig. 1. Main challenges and objectives on the path to higher levels of automation

At current research was validated safety during roadworthiness testing, while using campus closed area as a physical infrastructure. Before that the robot, road and surrounding landscape was digitalised and possible scenarios were simulated. Also, user awareness and acceptance of self-driving robots were topics of interest. In-vehicle technology enablers are described in more detail at next chapters.

Delft University of Technology [6] has implemented a 63-question online survey among 5000 respondents in 109 countries assessing correlation coefficients with the countries' objective road safety statistics and countries' developmental status in terms of education and gross domestic product (GDP) per capita. However, since the highly and fully automated vehicles are not available yet, the results of the survey comes more out of participants' imagination of the future automation and should be only taken as a reference.

2. SELF-DRIVING PLATFORM DEVELOPMENT

Platform design is shown in Fig. 2. All moulds and panel frames are specifically designed for this project. Body design of the platform takes also into account a location of sensors required for the autonomous cruising. Sidebar lights are implemented by using

RGB LED matrix where all individual LEDs are independently driven. It means that the vehicle can easily change lights from red to white on both ends as well as signal custom figures separately in any light panel. The LED element is the main HAVI device communicating with humans. The vehicle has the following technical parameters as shown in the Table 1.

Fig. 2. Electric autonomous robot platform design

One of the intentions of the project was to keep the development open and make the project accessible to new developers and students. An open source software platform is critical in that respect. The main software framework is Autoware which is an autonomous driving stack running on top of the Robot Operating System (ROS).

Table 1. Last-mile autonomous robot platform

Type	Cargo or passenger
Cruising speed, km/h	20
Turning radius, m	9
Main motor, kW	47
Battery, kWh	16
Dimensions	
Height, m	2.3
Length, m	3.5
Width, m	1.3
Sensors	Pieces
LiDAR Velodyne VLP-16	2
Safety LiDAR	1
Ultrasonic sensors front and back	8
Short distance radar	1
Cameras	8
RTK-GNSS	1
IMU	1

As AVs can pose a danger to human life, special attention was targeted to the system and integration testing of the software [7]. The platform software architecture and message flow is shown in Fig. 3.

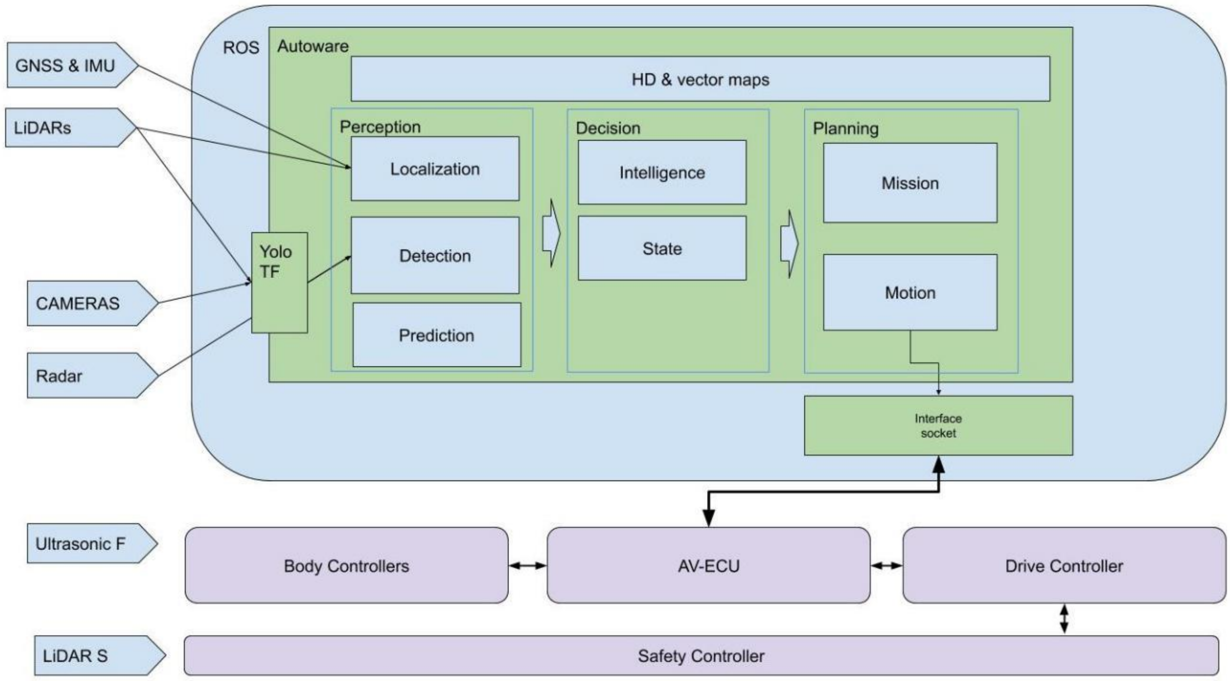


Fig. 3. Autonomous platform software architecture and message flow

The platform takes inputs from following types of sensors:

1) LiDAR, radar and camera inputs are used for localization, obstacles detection, object classification and safety;
2) Global Navigation Satellite System (GNSS) is used for localization correction;
3) Ultrasonic sensors are used for manoeuvring and second level obstacle detection
4) Output commands are steering angle and linear velocity which are sent to the low -level controllers over UDP messages.

The robot platform has four Basler Pylon cameras for object detection tasks. One in the front, one on the top and two on both sides. A ROS package for real-time object detection based on YOLO is applied for object detection.

The pre-trained model of the convolutional neural network can detect pre-trained classes including the dataset from Pascal Visual Object Classes (VOC) [8] and Common Objects in Context (COCO) [9]. This package publishes number of detected objects and their position. Based on detected and classified objects the platform changes the lights according to identified humans.

Lights on the platform are designed with the idea of being able to display different symbols for the humans in addition to the regular lights. This gives to the humans a better idea of what the vehicle does or plans to do. To achieve this, a custom light is designed, consist of 512 red, green, and blue (RGB) light-emitting diode (LED) as a LED matrix module.

The LED matrix module is covered with a diffuser and the assembly is located behind the windscreen back and front. The LED matrix module is based on WS2812 intelligent control LEDs. Each LED can be independently addressed as an RGB pixel that can achieve 256 levels of brightness and 16 777 216 colours in total with a scanning frequency of 400 Hz.

All RGB LED matrix modules are controlled by dedicated electronic control unit (ECU). The module ECU supply a high current 5 V power to the LEDs and drives all LEDs individually. All four modules ECUs and a light control ECU are connected on the vehicle CAN bus where messages of requested light behaviour are received. A PC sends status messages through a master controller to light control ECUs which generates specific messages to each LED modules (Fig. 4).

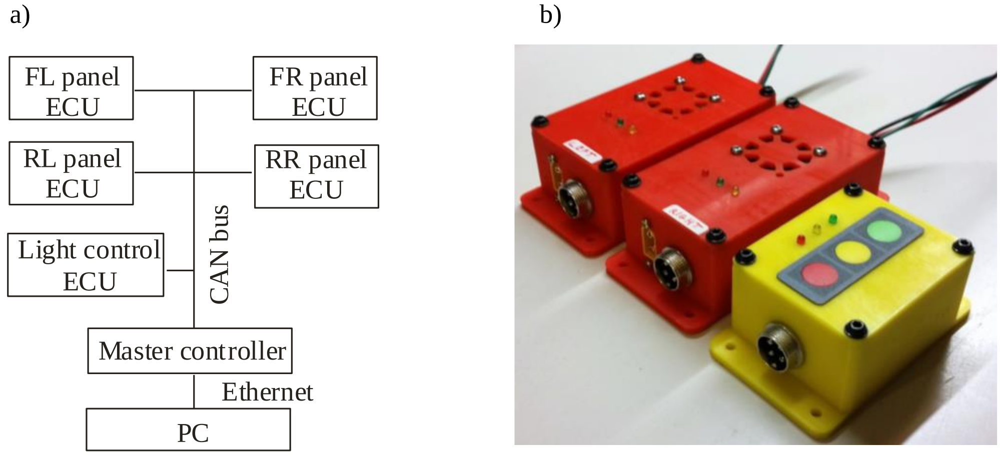


Fig. 4. Hardware architecture (a) of two panel electronic control unit (ECUs) with light control ECU and light control ECU module (b)

3. HUMAN-AUTONOMOUS VEHICLE-INTERACTION (HAVI) EXPERIMENT

3.1. EXPERIMENT DESIGN

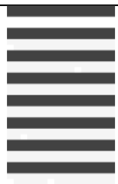
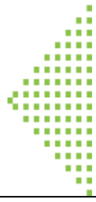
With the existing robot platform and the current researches going on [7, 10, 11], it is necessary to go further into the communication between human beings and AVS [12]. The aim of this experiment is to gather the knowledge about:

1) What's the attitudes of people towards the general safety of autonomous driving technology?
2) How do people feel about the interaction with driverless vehicles especially the campus shuttle minibus?
3) How to bring up a universal human-machine language for more harmonious interactions?

Since a single LED panel is illuminated by 16×8 px, three patterns are chosen to be finally transplanted onto the robot platform as shown in Table 2. Performance of designed line patterns is shown in Fig. 5. Arrows pattern (Fig. 5a) address a message for human to start crossing the crosswalk and indicates Zebra Line pattern (Fig. 5b) while human crossing crosswalk.

A questionnaire was created to collect feedbacks and personal data from humans interacted with robot platform. The factors mentioned in the questionnaires are mostly based on the previous studies on AV. In [13] gender difference was found to strongly affect the trust of whether AVs can make a correct decision and stop for humans via their technology. Authors in [6] claim that typically, younger people express a more positive attitude towards automated vehicles however, as age increases, risk acceptance decreases [14, 15]. People with higher educational backgrounds tend to be more favour of AV than those less educated as shown in [16]. In terms of Industry 4.0 state of the art research has been successful in development of digital twins of industrial robots [17]. The AV have enormous potential to be tested and developed as digital twins regarding human-machine interface as well.

Table 2. Illustration of light design pattern for the HAVI experiment

Pattern	Zebra Line	Arrows	Cross
Action	Pass	Pass	Stop
Visualization			

a) b)

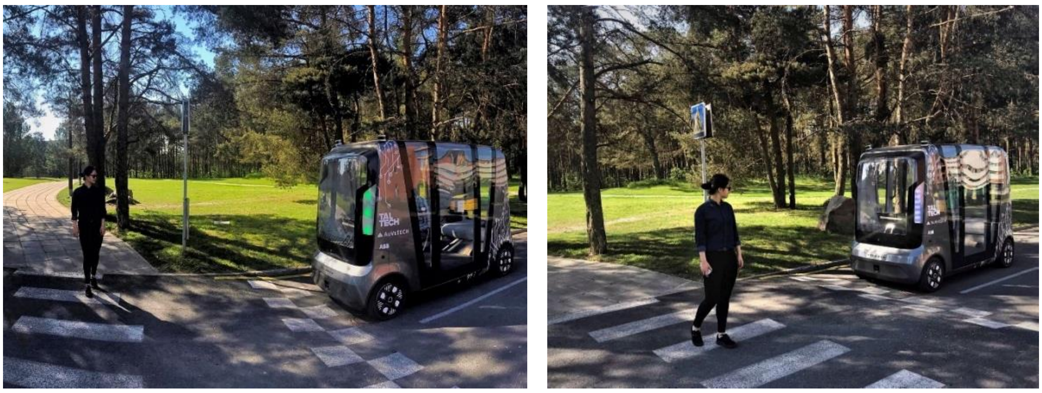


Fig. 5. Performing experiment with pattern Arrows (a) and Zebra Line (b)

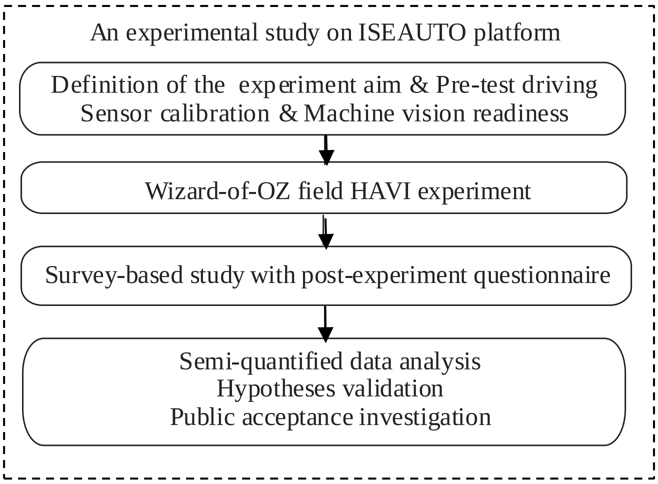


Fig. 6. The experiment plan on robot platform

Experimental HAVI study plan on robot platform is shown in Fig. 6. All test driving was mostly operated during daytime on the designated roads in the university. There were clear signs at the crossroads where interactions happen between humans and the vehicle near the zebra line. Participants in the experiments were randomly chosen when humans are crossing the road and a following questionnaire will be filled by the human.

3.2. THEORETICAL ANALYZING MODEL

To better reveal the mechanism of this HAVI experiment, the initial TAM concept [18] (Fig. 7a) as a base and some other related models applicated on AVs [19, 20] have been studied to help build up our technology model (Fig. 7b) thus analyse the necessity of the whole experiment. Questions covered in the questionnaire are also designed out of the intention to collect data for validating the model.

The initial trust (IT) has been studied in human-automation interaction [21] as a key element [22] and there has also been empirical support in AV filed [23] about the drivers' trust in the technology. However, the trust from the humans hasn't been widely introduced to the assessment of the HMI design on AV. A German version questionnaire named Trust in Automation (TiA) was adopted for exploring the trust in autonomous driving where five subscales: Reliability/Competence, Familiarity, Trust, Understanding, Intention of Developers built up the criteria. However, most of the current researches are discussing IT in the autonomous technology itself instead of viewing from the efficiency of interactions between human and AV.

Prior beliefs and experiences are based on empirical evidence acquired by means of the senses, particularly by observation and documentation of patterns and behaviour through experimentation [24]. As mentioned in the research targeting human behaviour, humans often make risky decisions in assessing the danger that vehicles pose [25]. Those decisions are generally made from their previous experience and empirical knowledge (EK).

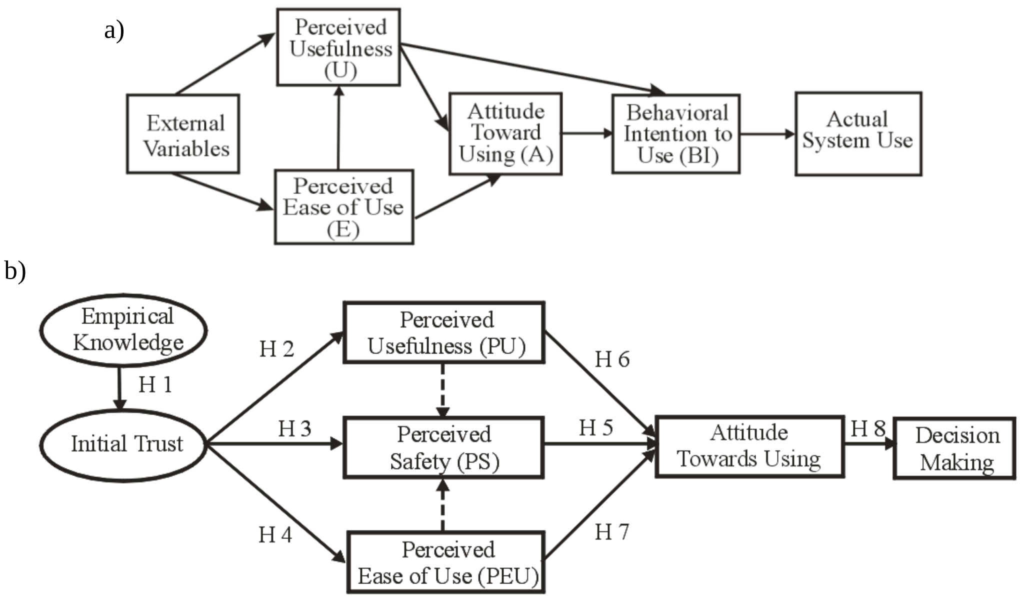


Fig. 7. Original TAM contents (a) [18] and model proposal of HAVI experiment (b)

Attitude toward Using (ATT) refers to an individual's positive or negative feelings towards using a technology. People with a positive attitude towards a technology tend to have a higher intention to use it [26].

Perceived Usefulness (PU) was defined as degree to which a person believes that using a particular system would enhance his or her job performance [27]. Under the current circumstance, it's hard to promise the decision accuracy of AV when it encounters other road users especially humans who are more vulnerable. Although the autonomous technology has been developing for decades but accidents are still inevitable when it's hard to predict human behaviour and relate it a similar context for AV to understand.

Perceived Ease of Use (PEU) was defined as extent to which a person believes that using particular system would be free of effort. The hardest part of HMI design on the vehicle is to make sure the message is well delivered and understood by receivers in both ways. For one thing, the vehicle can present its understanding of the road condition via the LED lights on. For another, the humans can notice the lights and make right decisions to ensure their own safety.

The attitude towards the HMI design on the AVs can directly reflect humans' acceptance of the designing concept and it is also the basis of validation on this road safety approach. To create a common language between human and AV, it's easier to make the vehicle more human-like instead of changing people's mindset for understanding the machine [28, 29]. The result of Decision Making (DM) helps to assess the whole experiment whether the interaction improves mutual understanding and lower the risk of fatal collision and misjudging.

The main conclusions as hypotheses in this model are empirical knowledge is strongly related to Initial Trust, that has positive effect on Perceived Safety, Usefulness and Ease of Use; which in turn has a positive effect on Attitude toward Using that is strongly related to Decision Making.

1) H1: EK is strongly related to IT.
2) H2-H4: IT influences PS, PU and PEU and PU, PEU both link to PS.
3) H5-H7: PS, PU and PEU influences ATT.
4) H8: ATT is strongly related to DM.

4. ANALYSIS

To better ensure the safety during the operation, although the robot platform is able of fully autonomous functioning, when carrying out the experiment, a human driver still sat in the car using controller to manipulate the driving. However, the operator himself pretended to be a passenger and hid his hands without being spot to manually drive the self-driving car. Thus, the experiment was using a Wizard-of-Oz method for HAVI and according to the survey afterwards, all the subject participants reckoned the car was in autonomous mode. Thus, for an experimental study, this approach doesn't affect the actual results since safety is the priority during the experiments.

Respondents divided equally between male and female, giving a good example for non-bias analysis and to avoid the gender influence. However, when comes to the feeling towards the interaction with AV, the results surprisingly almost present a tie between being absolutely fine and cautious. Colour signals are preferred as the message delivered during HAVI by most of the participants. However, due to its new trial on HAVI, the lights design of the platform was only clearly understood by half of the respondents while the rest were confused or had no idea of the meaning. The full results are presented in Fig. 8.

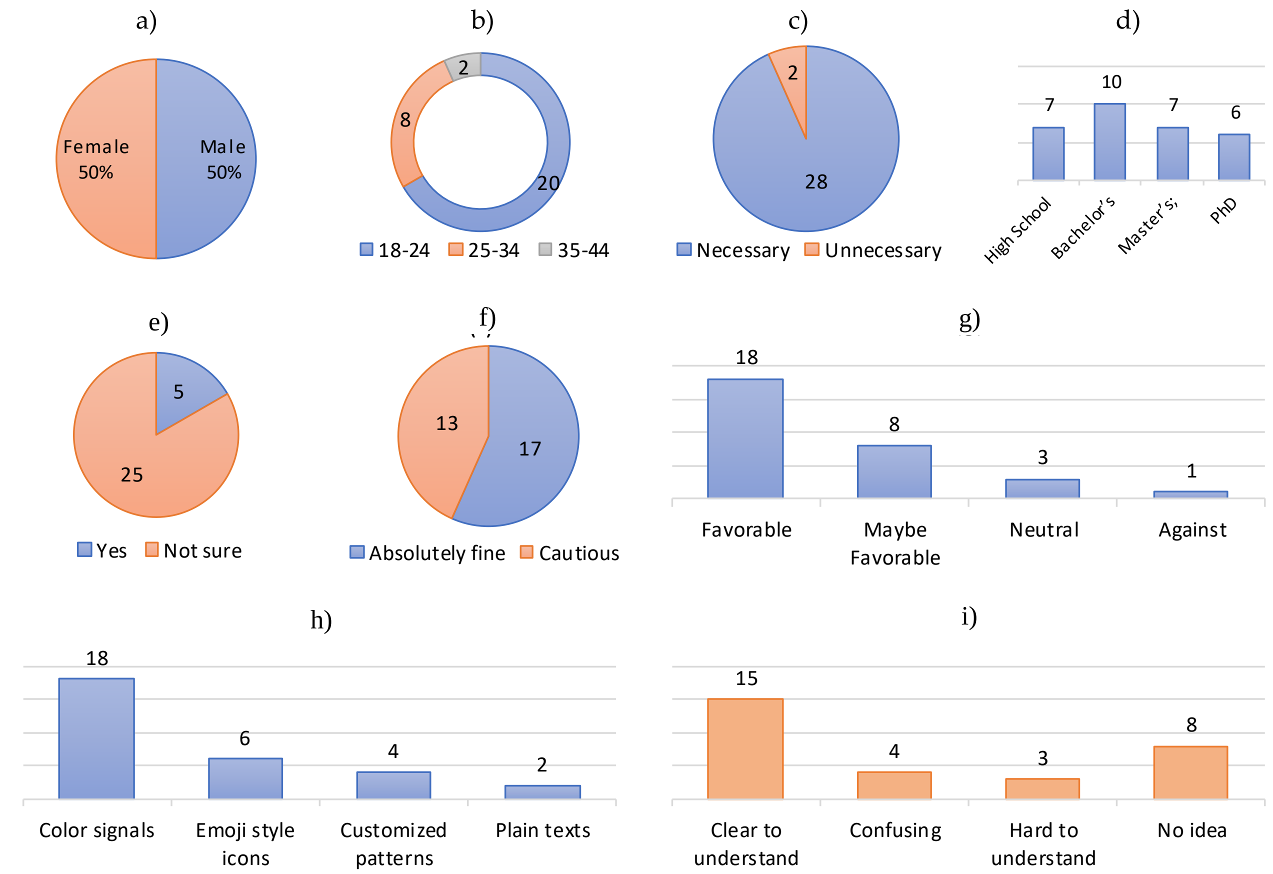


Fig. 8. Results of the survey: Gender (a), Age (b), Opinion towards the necessity of HAVI experiment (c), Level of education (d), Willingness of sharing roads with AV (e), Feeling towards the interaction with self-driving vehicles (f), Attitude towards driverless vehicles on the roads (g), Preference for the message type during an interaction (h), Feedback of platform lights Design (i)

Combined with the model proposed before, the results can be further analysed for each hypothesis in the previous chapter.

1) The education level and the age can both reflect an individual's knowledge basis and affect their perception on the surroundings. Telling from the statistics, younger people with less education experience tend be more favourable towards AV and open to share roads with them while older generations with higher education tend to have more concern and appear to be reluctant to the trendy technology. They prefer to wait and observe until the readiness of mature products in the market.
2) Those who trust more in AV also tend to feel it more necessary to carry out HAVI experiment and positive attitudes towards AV can bring them more confidence during the HAVI. Also, the acceptance of the technology affects people's choice on the product/ technology design, here was the preference for the message type.

Besides these, better interpreting of the pattern and the activeness of engaging in HAVI can help the individual feel less stressed during the experiment.

3) Participants who also are the end users of the product/technology are achieving a more successful interaction. It has meanings from both sides where on one hand people should feel ease to understand thus make next-step decisions when seeing the lights, while on the other the car should make the most of the lights to harmonize HAVI process.
4) A commonly accepted machine language, car lights in our case, can increase the chance of people to accept the technology. HAVI has two main bodies, namely the human and the autonomous vehicle, so either side fails to pass through their understanding would lead to a bad decision making. The algorithm can optimize the decision made by vehicles via machine vision while this information should be perceived by human beings.

5. CONCLUSIONS

The HAVI experiment described above on self-driving electric vehicle was carried out in campus area thus the result of the experiment is somewhat site specific. However, by taking usages of the educational research vehicle, this HAVI experiment provides an approach to improve road safety for AV and help researchers to get an overview of how people react to the concept of creating a common language between humans and AV. In practice remotely controlled multi robot environment as tested in [30] can be implemented also for larger mobile autonomous robots used in HAVI experiment.

With the increasing number of robotised AVs, more effort from all sectors is needed and emphasized to ensure safety. One of the goals of the paper was to develop a novel on-vehicle light design which can inform humans of the real-time decision made by robotised AV. Sensors on an AV should correctly identify humans and deliver a clear information in time indicating its movement.

This research consists two parts: a series of field experiments and a questionnaire-based survey right after each independent experiment. It’s notable that the importance of safety always comes first when people encounter AV unexpectedly and have to instantly make a subconscious decision during the interaction. It is also clearly seen out of the experiment that the communication between AVs and humans needs to be taken much more seriously by vehicle manufacturers as well as research institutions. AV without a driver is much more challenging than expected. Defining a universal and simple driving HAVI is clearly not sufficient. Visual signalling in combination audio and other possible channels need to be experimented and designed for future autonomous vehicles.

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