Perceived Pedestrian Safety: Public Interaction with Driverless Vehicles

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***Abstract*— Trust plays a decisive role in the public's acceptance of the new self-driving car technology. In order to better understand how to promote confidence in vehicle automation safety among the public, we studied pedestrian behavior shortly before and while crossing a marked crosswalk. Such information is also essential for setting parameters for automated vehicles to act accordingly during interactions with pedestrians. Through the analysis of the recorded videos and subjective qualitative data, we identified factors that potentially influence the perception of a road situation as safe in an environment in which vehicles operate with full driving automation (level 5) in a public space. A variety of responses were observed that exhibit several levels of trust, uncertainty and a certain degree of fear. It became clear, however, that the longer the people interacted with the vehicles, the more confident and trusting they became in automation capabilities. The existence of a communication system to interact with driverless vehicles was also evaluated as positive.**

I. Introduction

The Society of Automotive Engineers [SAE] describes in its recommended practice SAE J 3016-2018 motor vehicle driving automation systems and defines six levels of dynamic driving task (DDT) performance, ranging from no driving automation (level 0) to full driving automation (level 5) [1]. The automotive industry and the research community are rapidly advancing towards fully developed autonomous vehicles. To cite some examples, Audi was recently able to let one of their vehicles drive autonomously about 900 km from San Francisco to Las Vegas, while in 2015 Google's multiple autonomous vehicles drove a total of 1.6 million kilometers in the United States. Under the name "Firefly" Waymo presented in 2015 the first autonomous vehicles that do not need to be converted and that have neither pedals nor steering wheels. In 2017 a Chrysler Pacifica hybrid minivan was added to the fleet, being the first autonomous vehicle developed from a mass production line vehicle [2]. However, most of the autonomous vehicles on our roads are prototypes [3] and the majority of autonomous vehicles currently in operation can be found on factory premises. They are used to transport goods or persons within the boundaries of the site itself. This is mostly to reduce personnel and time-related costs, as these vehicles are able to complete certain tasks much more expeditiously. In this kind of environment the human-machine interactions occur under relatively controlled conditions as the operators are familiar with the vehicles and the way they function. In contrast, the existence of driverless vehicles on the roads is still surprising and leaves room for unexpected situations as well as reactions from the other road users. Therefore there is a strong need to develop communication paradigms that can be understood by both sides.

Most scientific works that have been dedicated to the subject of autonomous driving deal with the factual assessment of individual vehicle components or driving assistance systems in terms of their competence and safety.

How autonomous driving could affect human mobility on the whole has also been explored in some works, where it is often stated that participation in public life can be increased by the reduction in restrictions to mobility that automated vehicles offer [4].

Other works discuss the profile of future autonomous vehicle (AV) customers as well as other unknown social and cultural consequences of increased AV usage, such as a potential growth in population relocation to suburbs and the fact that AV will compete with the use of public transportation due to their relative comfort and privacy [5].

Qualitative data has been also acquired through a variety of early-stage display concepts for interfaces [6] or through surveys in several studies on the subject, as for example in [7], a work that presented personal and psychological factors of trust in automatons. It refers to the extensive literature presented in [8] that defines the topic of trust compiling, as well guidelines for Human-Robot Trust Interaction.

Another basic question addressed in surveys was whether autonomous vehicles scared people [9], the percentage of respondents answering yes being 52% in Germany and China, 42% in Japan and 66% in the United States. The proportion of respondents that doubted a reliable functioning of the autonomous system was the highest in China with 74%, followed by USA, Germany and Japan with 50%, 48% and 43%, respectively.

In order to study the benefits to society and to help developers optimize the vehicles and continue to integrate autonomous mobility in the transport network, several large-scale pilot projects in autonomous driving were initiated in 2017. Examples include the "DriveMe" project, where 100 self-driving Volvo cars will be driven on public roads in Gothenburg [10], and the "Early Rider" program from Waymo, where anyone will have the opportunity to use an autonomous vehicle in an everyday situation. The user/users of the latter program are provided a platform to present

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their experience and thoughts about autonomous vehicles and share them with the world [2].

Many studies have examined pedestrian interaction with manually-controlled vehicles and have successfully identified some behavior patterns. In a research work with more than 650 pedestrians over a period of approximately 240 driving hours, it was shown that, in general, drivers will advance cautiously and slow down as they approach pedestrians. Similarly, pedestrians slow the speed of their gait and turn their heads to check if it is safe to cross, continuing on their path if so [11]. In an additional work performed in Austria, participants in a study were asked to complete an adapted 10-item version of the Self-Report Habit Index (SRHI). Results indicated that respondents very often crossed the road even as vehicles were approaching, while crossing the road at crosswalks was not a strong habit [12]. In line with this the authors in [13] conducted a field study comparing the behavioral response by using a Wizard-of-Oz prototype.

As trust plays a decisive role in the adoption of the new self-driving car technology [5], the authors in [14] increased the visual situational awareness of vulnerable road users (VRU) regarding the nearby location of both autonomous and manually-controlled vehicles in a user-friendly form to boost confidence in automation.

In order to identify the factors that influence the perception of a road situation as safe in an environment involving vehicles operating with full driving automation (level 5) in a public space, we studied pedestrian behavior before and while crossing a marked crosswalk (the kind without traffic lights). This information is also an essential element for programming the vehicles to act accordingly in such situations. It is also necessary that the AV notifies the pedestrians that they have been detected and it is completely safe to cross. To this end we developed and tested several interfaces that facilitate interaction with VRU.

The remainder of the paper is organized as follows: section II delineates the development of the graphical user interface (GUI) to notify the detection of pedestrians; section III presents the experimental setup to perform a formative evaluation regarding the GUI perception; section IV describes and discusses the obtained results; and, finally, section V concludes the work.

II. GUI Development

To notify the pedestrians that they had been detected and give them the signal to cross (or not), a GUI was developed by applying a variety of libraries in C++ for integration with the Robot Operating System (ROS) framework. The graph of connections in the network of our system contains the "hmi" package that includes the node in operation "hmisubscriber". This node is responsible for performing all functions related to the visualization of messages. It is connected via the topic "icab1obstacle_treat_bool" to a node from another package, which was already previously installed in the autonomous vehicle (see Figure 1). To avoid distortion and pixelation, images with the appropriate size were created depending on the screen resolution. To convey to the pedestrian the message regarding the proximity of an AV the created package received a message in order to decide which image was appropriate. Figure 2 depicts the developed system.

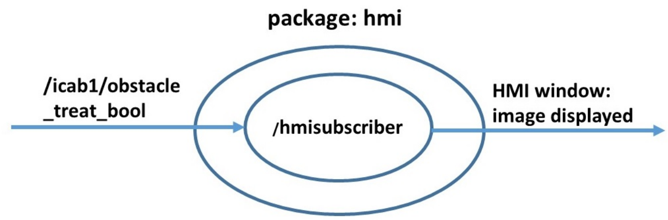

Fig. 1. Representation of the package developed in ROS

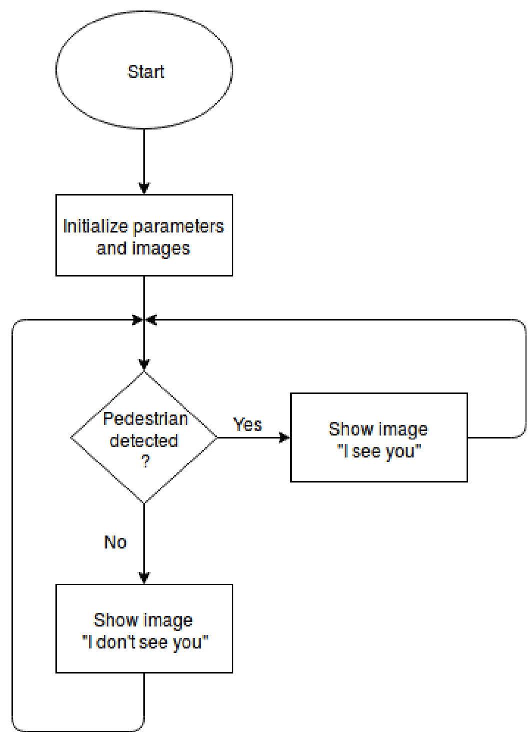

Fig. 2. State diagram of the developed system

The proposed human-vehicle interface consisted of a screen placed on the autonomous vehicle that faced the pedestrians so it could communicate with them by showing different images depending on whether the pedestrians had been detected by the sensors or not, as the vehicle acted accordingly by either stopping and yielding the way or by continuing driving. With this configuration, three different cases were proposed and tested.

1) Baseline: A first test was performed without any interface, in order to obtain results that allowed us to know if a potential communication between vehicle and pedestrian could be of importance.
2) Colors: red and green were the colors of choice to

convey to the pedestrian the message of whether it was safe to cross or not. The paradigm was inspired by standard traffic light color coding.

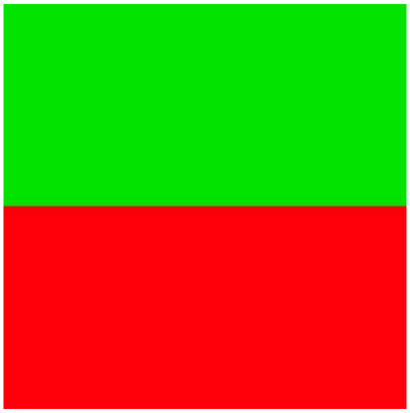

Fig. 3. Image conveyed by the AV to signal detection/no detection of pedestrian with green/red colors

3) Eyes: Inspired by real life situations in which making eye contact with the driver of the oncoming vehicle is essential to pedestrians at marked crosswalks, we emulated this interaction with an image of two eyes opened (I see you) and an image showing two eyes closed (I don't see you), as illustrated in Figure 4. This idea has also been adopted by the industry in several prototypical designs [15].

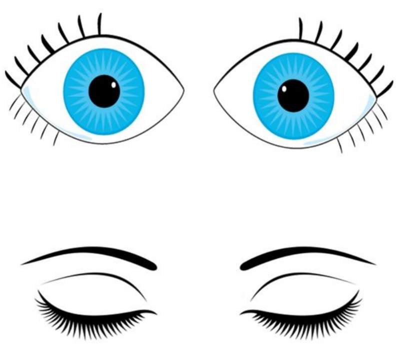

Fig. 4. Image conveyed by the AV to signify detection/no detection of pedestrian with open/closed eyes

III. EXPERIMENTAL SETUP

In order to gain the first insights regarding validation and improvement of the proposed communication interface, a formative evaluation was performed by a set of experiments with pedestrians. The goal was to study pedestrians' reactions to upcoming vehicles and to the conveyed messages.

To measure pedestrian response to driverless vehicles, we defined a tailored urban scenario with speed limits of 20 km/h according to the traffic law. The autonomous vehicle drove a predefined route of 100 meters length multiple times. Along this route, several pedestrians crossed in front of the AV and interacted with it without knowing they were being part of an experiment. The participants that showed more interest for the vehicle were asked to fill in a post-task questionnaire regarding their subjective experience with the system. The items in the questionnaire related to the familiarity of the respondent with autonomous vehicles, crossing behavior and conveyed messages clarity and understanding by referring to the images shown during the experiment. Pedestrians' reactions to the vehicle were also recorded with one of the cameras located on the vehicle. The camera could be perceived by any person and we assumed some people were aware of being filmed. At the same time, the fact that the vehicle was not driven by a human was clearly evident.

In the course of the documentation and analysis of the various reactions, we annotated responses regarding the effect of the vehicle on the participants.

A. Platform

The platform used to test this interface was iCab [16]. iCab is a research platform that consists of a modified golf car that can navigate autonomously. The vehicle is equipped with optical wheel encoders, a stereo-vision camera, a laser-range finder, a compass and GPS sensor modules, all of which allow autonomous behavior and detection of obstacles [14]. Pedestrians can be detected so that they can be avoided. Additionally, the vehicle stops if it detects an obstacle in a range of 3 meters from the laser. A touchscreen inside the vehicle makes it possible for potential passengers to interact with the platform. For our tests, this screen was placed on the front of iCab, facing the pedestrians. This screen (23 inch and 250 cd/m^2), shows the interface design presented in Section II.

B. Scenarios

The location in which the experiments took place was the Universidad Carlos III de Madrid campus in Leganés. It is an off-road environment where normal vehicles cannot circulate, but rather only pedestrians, slow delivery vehicles and iCabs are allowed. We selected a path where the iCab could drive autonomously along with pedestrians. The specific street is frequented by students from the University as well as by residents from the town of Leganes, who were assumedly not familiar with the research on autonomous driving. Figure 5 depicts a moment of the experiment in which a pedestrian makes eye contact with the screen on the AV.

C. Sample

Several pedestrians were exposed to the autonomous vehicle over two days, during which data was recorded. A total of 22 videos documented various behavior, including certain notable reactions, of 49 pedestrians.

As for the subjective evaluation, a total of 40 pedestrians responded to the questions in three groups designated as "baseline", "colors" and "eyes", described in section II.

Fig. 5. Experiment illustration depicting a pedestrian crossing in front of an AV.

IV. RESULTS

A. Video Analysis

From the video analysis a variety of reactions towards the iCab could be noted. Some pedestrians did not seem to realize that the approaching vehicle was not human-driven. Many pedestrians were so involved in the manipulation of their smartphones that they were not paying attention to their surroundings and were suddenly surprised by the vehicle. Several reactions indicated uncertainty as the individuals hesitated before crossing the street. This was particularly the case when the vehicle was not advancing in a straight path.

If the AV drove along a straight path, many people looked at it with curiosity, but as soon as the vehicle moved to the right or the left side, pedestrians looked concerned and avoided confrontation.

The AV appeared to be very interesting for most pedestrians, as it attracted their attention and curiosity. Many of them took pictures or videos. In many cases, people smiled and sometimes they even tested whether the vehicle really stopped. Contrary reactions could be appreciated as well: some pedestrians attempted to take a closer look at the vehicle while others did not dare to approach it.

As a result of the video analysis, a total of seven clusters could be distinguished and are listed below. These clusters were further classified into positive, neutral and negative responses as shown in Table I.

Four of the categories were classified as positive reactions. They accounted for approximately 51% of all reactions and included the following groups:

- ”smile”: all the people that smiled after seeing the vehicle
- ”interest”: all the people who had carefully examined the vehicle, after approaching it.
- ”test”: two persons who located themselves in front of the vehicle and tested whether it stopped.
- ”photo / video”: people capturing the moment

Reactions of persons that were willing to look at the vehicle were classified as neutral. About 24.5% of the persons were enclosed in this group.

Finally a negative attitude towards the vehicle was showed by two groups that appeared to avoid the vehicle. About 24.5% of the documented reactions were interpreted as negative.

- ”deviation”: stepping to the side, while the vehicle was approaching or by facial expressions such as raised eyebrows or movements of body parts to denote aversion.
- ”stand”: pedestrians that let the vehicle continue without attempting to cross. A total of five people were included in this group.

The difference between the percentage of positive and negative reactions was significant ($\chi^2(1, N = 49) = 7.26$, $p = 0.007$).

TABLE I
ANALYSIS RESULTS FROM THE RECORDED VIDEOS

Reaction	Positive				Neutral	Negative	
Distribution %	51.02				24.49	24.49	
	Smile	*Interest*	*Test*	*Photo / Video*	*Neutral*	*Deviation*	*Stand*
Number persons	14	6	2	3	12	7	5
Percentage	28.57	12.24	4.08	6.12	24.49	14.29	10.20

B. Subjective Qualitative Data

The qualitative analysis of the data gathered through the questionnaire delivered the following results that have been summarized as follows.

1) Baseline Condition: None of the participants in the experiment had ever interacted with the driverless vehicle, although some of them said they had seen the vehicle on campus before. Regarding crossing behavior, only 9% of the participants waited until the full stop of the AV, while the rest crossed when the vehicle was decelerating. Hesitations regarding crossing behavior were evaluated on a 5-point-Likert scale, by which low scores denoted less hesitations and high scores more hesitations. In the baseline condition, the mean value for hesitations was 1.91, with 27% of the participants responding that they did not hesitate when crossing. Under the possible reasons for uncertainty were the lack of knowledge about whether the vehicle had actually detected them, whether the vehicle was going to slow down and also not trusting the functioning of the sensors.

2) Color Coding / Open/Closed Eyes Condition: Responses regarding the messages in Figure 4 with open and closed eyes (conveyed by the AV to indicate awareness of pedestrians) showed that the majority of the participants (62%) saw the image in the attached monitor. From those that saw the image, 50% considered the message to be clear, 25% did not recognize the message and 25% did not know.

As for the message with red and green colors, 67% did not understand the message intended versus 33% of the respondents who stated that whether they should cross or not was clear to them.

Comparing the two proposed images (color-coded and open/closed eyes), when asking people to choose which image was more understandable 70% of people preferred the eyes image compared with 30% that selected the color-coded. These results did not indicate a significant preference ($\chi^2(1, N = 21) = 7.54$, $p = .006$).
Using the proposed interface combining both types of signal (eyes/color) hesitations when crossing on a scale from 1 to 5 were slightly reduced to a mean value of 1.8 (*SD*=1.34) in contrast to 1.9 (*SD*=1.37) without the interface (Figure 6). This effect was not significant, ($t(41) = 0.69$, $p = 0.24$). The percentage of people that said that they did not hesitate when crossing was increased from 27% from the baseline condition to 35%, showing a tendency for the pedestrians to feel safer when the interface is activated. This effect was however not significant ($\chi^2(1, N = 42) = 0.29$, $p = 0.58$).

In addition, no one responded with higher values of hesitation (4 and 5). However, the proportion of pedestrians that waited until the AV fully stopped before crossing was 9% both with and without an interface.

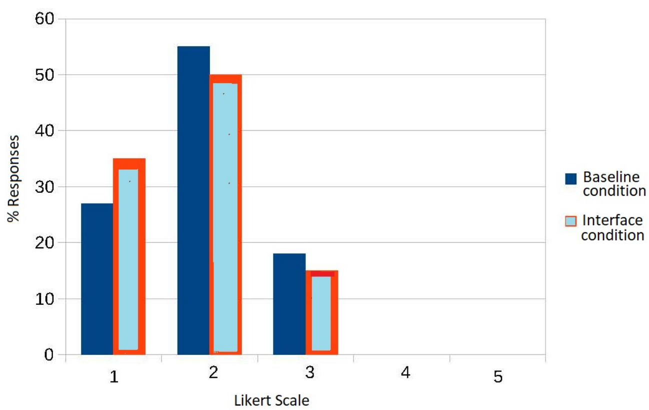

Fig. 6. Hesitating crossing behavior for baseline, colors and eye conditions as described in section II according to subjective qualitative data. The 5-point-Likert scale ranges from 1 (no hesitations at all) to 5 (many hesitations).

3) Crossing habits: In both tests, baseline and with the interface activated, the results showed that the crossing habits in half of the respondents were to wait until the vehicle was completely stopped. The habits of the other half were not to wait. When asking if they looked for eye contact when crossing, in a Likert scale from 1 to 5 being 1 never and 5 always, the mean value was 4.1 (*SD*=2.53), meaning that people usually look at the driver's eyes to see if they can cross or not (Figure 7). Apart from looking for eye contact to be certain that they were seen, the respondents also considered the vehicle's deceleration before crossing. Another interesting fact was that some pedestrians were affected by the behavior of other vehicles and pedestrians in the surroundings when deciding to cross.

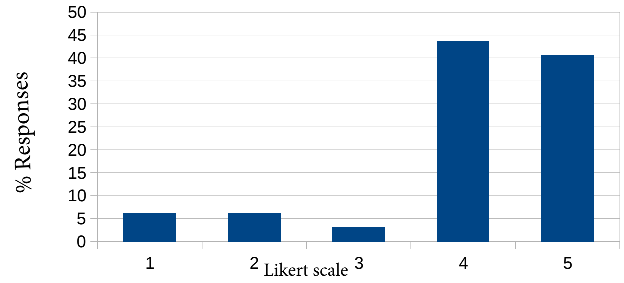

Fig. 7. Eye contact behavior before crossing. The Likert scale ranges from 1 (never) to 5 (always)

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As for the proposed interface, all participants agreed that showing an image with information regarding the acknowledgement of their presence as pedestrians from the side of the AV made them feel safer.

These responses confirmed the necessity of an interface that allows the AV to communicate with pedestrians in order to provide the level of safety required under the presence of autonomous vehicles in a public space.

V. Conclusion and Future Work

Results from the questionnaire and the video analysis showed a variety of responses that ranged from not trusting the vehicle and stopping as it approached, to completely trusting it. We could however observe that the longer the interaction with the vehicle the more confident they became regarding road safety and trust in the automation capabilities.

The majority of the participants in the experiment agreed that the existence of a communication system to interact with driverless vehicles was positive. It was interesting to realize that some participants were not aware of the existence of a screen in the vehicle and the messages that were displayed. This implies the necessity of measures to inform citizens about the presence of autonomous vehicles by different means. According to the results from the images displayed by the vehicle and the clarity of the message conveyed, results showed that it might be necessary to include another element to indicate pedestrian detection.

In terms of possible future developments that would improve the interaction between autonomous vehicles and pedestrians, we intend to extend the number and characteristics of participants in our experiments. For instance we will target in future work people with reduced visibility by adding sound warnings and intermittent lights with different frequencies of flashing and colors. Information regarding speed and other parameters that can help to assess safety could be also conveyed by different means, including the use of vehicle lights to project information, as well as information broadcast to mobile devices or to the infrastructure.

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