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Strategies for Negotiation between Autonomous Vehicles and Pedestrians

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Abstract

Autonomous cars seem on the verge to reality, with vehicle manufacturers presenting their first prototypes and the topic of self-driving vehicles being discussed in mass media. Until now, in individual traffic humans covered distances from A to B using a personal car or a motorcycle, riding a bike or walking by foot (from strongest to weakest modality). All these modalities coexist in parallel in typical traffic situations, and it should be clear that different situations require clarification and communication between the different road participants, e.g., to negotiate who has right of way and who has to wait. Many drivers spend a considerable time each day in their car – for commuting, shopping, and traveling. In order to save time for the driver it is expected that manual driving will be eliminated in the near future and replaced by automated systems. One of the problems not brought up by autonomous vehicle manufacturers so far is when the „strongest" road user (vehicle or truck) is no longer human-driven, as then the chance for vulnerable road users (VRUs) to communicate, interact and negotiate could be evicted too.

In this work, based on the showcase of Mercedes Benz's F015 at CES this year, we want to show that it is important to substitute the means of pedestrian-vehicle communication by autonomous cars to understand the signs and gestures of pedestrians and also communicating actively (e.g., using visual feedback on windscreen, bonnet or headlights) towards them. To get a deeper knowledge of this scenario, we will setup and conduct a user study, placing subjects into situations with a presumably autonomous car and comparing the actions and reactions with and without the car explicitly interacting with the subject. Our expectation is to detect a difference in the behavior of the pedestrians that will reveal a different level of trust and confidence towards autonomous cars.

Keywords

Autonomous driving, Mitigation strategies, Pedestrian-vehicle interaction, Vulnerable road users (VRUs), Negotiation concepts.

1 Introduction

In recent years, autonomous cars and the prospect that they will populate our roads in the near future have gotten more and more attention. At first it was Google taking self driving vehicles out of the laboratory and onto the streets, but major car manufacturers like Mercedes Benz, Audi, General Motors or Toyota caught up and presented their own concepts of self-driving vehicles. A clear trend towards autonomous cars and their product maturity in coming years can be observed. A major motivation for autonomous cars is the saving of lifetime for each individual driver, and another reason is the unpredictability and error-proneness of the human driver resulting in many (unnecessary) accidents. In 2014 alone, 47,670 people were injured in road traffic accidents in Austria und another 430 were killed (Statistics Austria, 2015). The long term ambition of the European union articulated as the "*Vision zero*" is to abolish road deaths and serious road traffic injuries (Lindahl, 2013). To achieve this goal, the EU follows seven priority objectives: 1) education and training, 2) enforcement, 3) safer infrastructure, 4) safer vehicles, 5) use of modern technology, 6) emergency and post-injury services, and 7) the safety of vulnerable road users.

While a lot of purely technical issues (mainly related to objectives 3), 4), and 5)) are already solved or expected to be solved in the near future, some new problems arise with the new circumstances, for example related to point 7) – which actually is the focus of this work: It aims at improving the communication between (autonomous) cars and VRUs with particular focus on pedestrians and with two main issues to look at:

- One problem is the lack of means of established communication between pedestrians (or other VRUs) and self-driving vehicles. With human drivers, information is communicated and situations are clarified by eye contact, or gestures using eyes, head or hands, sometimes with additionally using technical means like the headlamp flasher. Without a driver operating the car, this communication channel is (initially, i.e., before developing solutions or work-arounds) eliminated.
- Another slightly related problem is that the switch from manually driven cars to autonomous vehicles will not happen instantly, meaning to exchange all cars from one day to another. It is expected to take about 50 years (Litman, 2015) until the overwhelming majority of manually driven cars have disappeared from our roads, so both types will coexist for some time. Not only is there a similar situation between self-driving cars and drivers of a manual car as described above for pedestrians, but for all road users the same question "how to distinguish an autonomous car – from the distance – from a manually driven one?" arises. Is there a necessity for special shapes, colors or other forms of expression that help other road users tell the two kinds apart?

A confirmation for the importance of these problems was shown at this years' CES with the Mercedes F015 concept car, actually showing potential solutions: In one feature, which only is likely to work at night, a laser projects a crosswalk in front of the vehicle when it stops, in order to tell a pedestrian it sees them and is expecting them to cross in front (Figure 1, left).

It can also use LED’s to communicate its status (Figure 1, right), e.g., by showing words at the back for other cars (Templeton, 2015). In addition, there is plenty of research available picking up on the communication problem between the autonomous car and its operator, concerning for example communication channels (Löcken, 2014) or general user interaction schemes and driver or passenger experience (Mok, 2014).

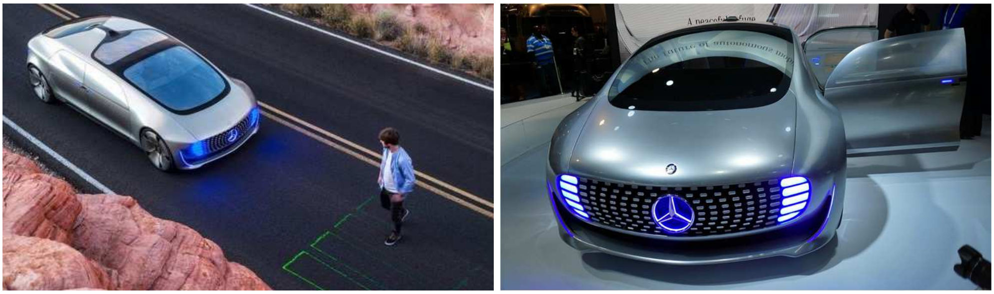

Figure 1: Mercedes F015 concept car projecting pedestrian crossing in front of the vehicle (left image; source: (Mercedes, 2015)). Mercedes F015 concept car with radiator grill „display“ to communicate with the exterior (right image; source: (Templeton, 2015)).

When it comes to the car interacting with other road users, related work focuses mainly on defensive measures. Google was for example granted a patent for a pedestrian leg protection airbag (Switkes, 2015), also Volvo and other car manufacturers already equip their cars with exterior airbags protecting pedestrians (Ferro, 2013).

The aim of this work is, however, to generalize on the concepts presented by Mercedes and other research institutions, which basically means to develop universal and generally understood concepts for negotiation between autonomous vehicle and pedestrians (or other VRUs). We are planning to study human (pedestrian) – vehicle interaction in a virtual reality (VR) environment, based on the followoing concrete interaction situations:

- **Situation 1:** Pedestrian aiming to cross a street at a pedestrian crossing (no traffic lights). How to negotiate with an oncoming autonomous car? When to take action and actually cross the street? What is the influence of the automation level on a pedestrian’s behavior?
- **Situation 2:** Person (just stepped out from a hotel) aiming at calling an autonomous taxi waiting on a remote location. How to call the taxi (e.g., using a waving gesture)?, How long does the gesture last?, etc.
- [**Situation 3:** (more general, not considered in this project) Does the feedback on the status of an autonomous vehicle (e.g., expect to stop, start to move off, etc.) using visuals on windshield, engine hood, lights, radiator grill, etc. significantly affect the behavior of a human interacting with it?]

The focus of this project is on the actions and reactions of a pedestrian when communicating with an autonomous car (situations 1, 2) rather than the actual means of communication. This intermingles with other disciplines, most notably psychology, as the actual scope of the study is the behavior of the human subject (pedestrian, VRU).

2 Concept

We want to show that a car actively communicating with a pedestrian does have a significant impact on the human interacted with, as opposed to a car that does not provide explicit feedback or status information. On that score, we want to conduct a study where we expose subjects to a presumably autonomous car, instructing them to perform two tasks (according to situations 1 and 2 above) with that car. As there are no real autonomous cars available for this study and the forms of interaction are yet to be explored, a „Wizard of Oz“-kind of setting will be used with a car controlled by a human.

Thinking further on the study setting, it is inherently important for the subject to believe the car to be a real, autonomous car. Therefore, it was initially planned to perform this experiment in a real world environment, i.e., masquerading a real car to act as an „autonomous“ car with hiding the driver from the pedestrians sight, adding some prototype camouflage with stickers and of course applying LED strips to the cars headlights to act as visual feedback to the user. To make this plausible, the system would have to be implemented in either some car show or car dealer event, or some Automobile Club’s subsidiary or at least some public, dedicated space to give the conduction of the experiment some frame of credibility. With respect to the available time and means, but also due to the urge for precise and reproducible measurements within the experiment we finally decided to take this experiment to the virtual world.

2.1 Experimental setting

A virtual environment experiment always comes with certain limitations. With VR headsets simulating the situation, the severe impact of a car hitting a human does not exist, which might lead the subject to act more careless than with a real car. Also, when acting and gesturing while not physically being in the simulated world might feel odd, and moving inside the real world while actually seeing the virtual one might be irritating to some test persons. We thus consider to borrow from augmented reality (AR) technologies to compensate for this awkward situation of measuring real world behavior which is triggered by virtual world activity. The Unity3D (Unity Technologies, 2015) game engine provides features to render 3D models into a marker-labeled real world environment captured with a camera. First tests using a Nexus 5 Android phone in a Google Cardboard (Google, 2015) VR viewer showed that this is fast enough and well acceptable for phone-camera captured video streams in almost realtime (the augmented image is rendered with only a very short delay), not causing dizziness as initially feared. This way the subjects will see themselves, their own hands, the experiment coordinator and the virtual objects the actual real world is augmented with. We hope that we can apply this technology in a way so to deliver a comfortable situation for the experiment.

On the other hand, there are various advantages that go beyond the mentioned time and means limitations that it overcomes. The biggest concern is to make the subjects believe the car to be a real autonomous one. While this would one of the biggest concerns in a real world experiment, it is rather easy to claim that in a virtual world where the virtual car is running the software of an autonomous car in a simulation situation. Also, the car's movement and other behavior can be totally scripted, with only a few decision points that depend on the user's actual behavior (for example the car not stopping at all, when the user does simply not act in the scene). Both acceleration and slow down of the car as well as the times it moves can all be exactly the same for all contestants, so no variation in car behavior would influence the behavior of test subjects. Last but not least, within a completely controlled environment an experiment is a lot easier to track and record for later analysis.

2.1.1 Procedure

Before the experiment, every subject (control group: no feedback from the vehicle; test group: visual feedback from the autonomous car) will be briefed about the two tasks to perform (according to situations 1, 2 above) and the entire scenario that he or she will go through during the study. A virtual reality headset will be used to put him or her into the virtual setting, which consists of a long stretch of road with a curve fading into the distance at each side, and a pedestrian crossing across the long stretch.

- **Task 1:** The subject will be first placed on one side of the pedestrian crossing and is obliged to cross the street while the car is approaching, indicating the urge to cross. The car will stop rather abruptly in front of the crossing, but indicating the intent to stop in the test setting while not showing any intent to stop until actually breaking in the control setting. Without the subject acting at all, the car will pass and not stop, the experiment will then be stopped early.
- **Task 2:** In this situation, the user, after having crossed the road, wants to call an autonomous taxi that is parked somewhere in sight of the subject. The car, once having understood the request, will not immediately start moving, but in the test setting indicating ahead of doing something that it is planning to pick up the subject. Again, not acting at all will not make the car move, and the experiment will be stopped after a timeout.

After each task a standardized questionnaire has to be filled, asking for qualitative feedback about the subjective experience (e.g., NASA TLX) of the task. In addition, a post-test questionnaire will be handed out to subjects, collecting general demographic information as well as feedback about the plausibility of the setting.

2.2 Expected results

As for the subjects actions and gestures, we expect them to be rather sweeping and explicit, which makes identifying the start and stop of the action rather easy. Spoken out/voice commands are not explicitely forbidden, but it is expected that most of the subjects will use finger/hand/head gestures to interact with the vehicle. Important is the timing when the subject will start and stop communication to the autonomous car, or start crossing the street with the car approaching. While the time the user starts to communicating with the car cannot be estimated, it is expected that the action will stop as soon as the car will use its visual feedback to communicate back to the user. This will result in a more determined and decided behavior of the subject, ultimately reinforcing trust into the new technology to come.

2.3 Summary

The setup will take the subject into two everyday situations he or she will most likely experience in the future on a regular basis. With focusing on the timings between actions – while actually moving the car ever the same way – we hope to show how important explicit feedback and interaction is to pedestrians and other (vulnerable) road users interacting with autonomous cars. We expect a more confident behavior of the human, and with gathering gesture information for a rough analysis based on classes it is expected to yield expansive motions – with further possibility for analysis in other disciplines.

3 Strategies for Evaluation

The subject will be video-taped throughout the whole experiment from two angles. With some kind of motion tracking – might this be some simple color coded visual 2D tracking from the video, or more sophisticated 3D tracking using dedicated hardware – all the performed/executed gestures will be recorded as well.

3.4 Qualitative analysis

The tracked gestures will then be classified into open (arms open, waving), closed (arms close to body, hands hidden), offensive (moving forward) and defensive (moving back, hesitating) poses – a complete set of classes is yet to be defined. From these classes we would like to derive how confident users are with autonomous cars: will closed gestures be considered sufficient?, will the situation be tackled offensively?

The video material will also be made available to other interested researchers for further and more elaborate studies on the actual behavior.

3.5 Quantitative analysis

More important (according to the aim of this project) is a quantitative analysis focusing on the action/reaction times between (autonomous) vehicle and subject (pedestrian): When does the subject start indicating that he or she wants to cross the street?, at which point in time – if at all – will gestures be stopped?, and when will the subject actually start crossing the street? A set of timings will be identified and used to compare the control and test settings.

4 Conclusion and Outlook

This project is a first attempt to explore how important it is to substitute current pedestrian-driver-interactions with other forms of explicit communication from self-driving vehicles. This is important to foster their acceptance among all road users, not just drivers. The virtual setting used for this study allows a very controlled quantitative analysis of timings, and certainly eases the qualitative analysis of gestures for further classification as the environment is entirely controlled. Classifying gestures and mapping the classes to a level of trust, and measuring times between actions and reactions will give us some insight on the importance that explicit communication of autonomous cars towards pedestrians pose.

That is just the beginning: On the one hand, we do not tackle different means of communication from the car to the VRU at all, but rather decide for one and compare its impact to the situation of providing no communication at all. This very communication channel alone will pose some hard problems to solve, as the requirements are plentiful: they should work all day long, from near to far distance and are ideally improving the current situation – catering all kinds of people, including visually or hearing impaired fellow humans. But not only the communication from the car to the human is of importance, also the other way round. While human drivers will understand all different kinds of gestures, autonomous cars will have to learn a possibly vast set of gestures and their different meanings according on the situation: does waving mean for the car to pull over, or to stop in front to let the pedestrian cross? What about police officers manually regulating a crossing? While obstacles, traffic lights, maps and other road users (including pedestrians) are currently considered for the pathfinding and moving of the vehicle, explicit control from outside – legally required, or simply due to the business interests of a taxi company – are yet to be discovered.

4.6 Expectations from the workshop

This work should be an impulse towards communication between autonomous cars and VRUs in general, which yet seems to have received little attention from the scientific community. If we have missed important contributions, we would be happy to be provided with other, applicable or even related work. We also hope to initiate a debate on the proposed situations, methods and quantitative measurements/qualitative analysis of the experiments, and generally receive additional feedback and other points of view on the general topic itself.

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