A Survey on Autonomous Vehicles Interactions with Human and other Vehicles

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Abstract: Autonomous vehicles (AVs) or self-driving cars have the potential to replace human-operated cars. AVs can sense the environment and even navigate some of the roads in conditions humans find challenging. This may quickly lead to people's overreliance on AVs and overconfidence that no failures will occur. Therefore, AVs can impact society positively and negatively. AVs are X-ware systems that consist of software, hardware, humans, and their interactions. Despite the large number of studies on AVs, there are still a large number of unsolved problems. One major challenge for AVs is communication with other vehicles on the road as well as pedestrians. Replacing some of the human-operated vehicles with AVs will require interactions between AVs and these other users of the transportation network. Most of the previous research efforts consider software failures, whereas few consider the role of humans in the current transition to a society in which self-driving cars predominate. This paper considers three points of view: I) the driver and passenger of the AV, II) pedestrians, and III) AV interaction with other users of the transportation network. We also discuss related studies on human behavior.

Keywords: driver-pedestrian interaction, human intention, behavior analysis.

1. INTRODUCTION

Technological advances, such as artificial intelligence, are being leveraged to build our future smart cities with the intelligent infrastructure in which driverless vehicles will be the key feature of the transportation network. Commercial cars are categorized into 5 levels [1], including: (i) Level 1 cars which are entirely manual; (ii) Level 2 cars in which only single operations such as anti-lock braking, brake assist, and electronic stability are automated; (iii) In level 3 cars, called combined function automation, two or more functions are automated; (iv) Level 4 cars are those which do not require attention of the driver at any time because they use automation to control all aspects of the driving task for extended periods; (v) Finally, level 5 cars are driverless and completely automatic. Nowadays autonomous vehicles (AVs) or self-driving cars (level 4 and 5 cars) are in the research spotlight in academia and of great interest to giant companies such as Apple, Google, Tesla, Uber, and Volvo [2]. AVs can sense the environment and navigate the roads even in conditions that are challenging for humans to manage.

There have been numerous successes, since the early attempts at autonomy [3] and several studies on autonomous vehicles have been published. Since 2004, the Defense Advanced Research Projects Agency (DARPA) has held three major challenges on robotic vehicles [4]. In 2007, the DARPA urban challenge focused on the research and development of robot cars for urban environments, which had to navigate moving traffic safely while obeying California traffic regulations. However, they excluded pedestrians and bicyclists [5] in their research. Later, Nothdurft *et al.* [6] introduced "Leonia" in the Stadtpilot project, an autonomous vehicle, which demonstrated the ability to drive autonomously in real urban conditions. They discussed the legal issues of driving AVs such as the role of driver, safety, and control concepts. Mark *et al.* [7] reviewed some of the main technologies and architecture of autonomous vehicles, and brought some of the emerging challenges and opportunities into consideration, including navigation system, software integration, and algorithmic integration. Bagloee [8] reviewed the challenges and opportunities that autonomous vehicles might create and, discussed the possible advantages and disadvantages of the AVs. Bimbraw [9] reviewed the basic chronology of autonomous vehicle technology. Tian *et al.* [10] proposed a tool for automated testing of a Deep-

Neural-Network-driven Autonomous Car capable of detecting behavior that could lead to crashes. Panichella *et al.* [11] proposed a technique to detect the feature interaction failures in context of autonomous vehicles by developing new search-based test generation algorithm.

Despite the large number of studies on AVs, the research on the interaction between human and AVs is scarce yet indispensable [12]. Driving in an urban area is challenging because there are more pedestrians in this area, which requires special considerations for AVs to be compatible in such an uncertain environment. Moreover, AVs must interact with the other users of the road and human-operated vehicles. Therefore, it is crucial to consider the challenges that driver and AV's passengers, pedestrians, and other users of the transportation network will likely face (Figure 1). This paper reviews the relevant literature on these three areas with special focus on providing a better understanding of the role of human interaction with AVs.

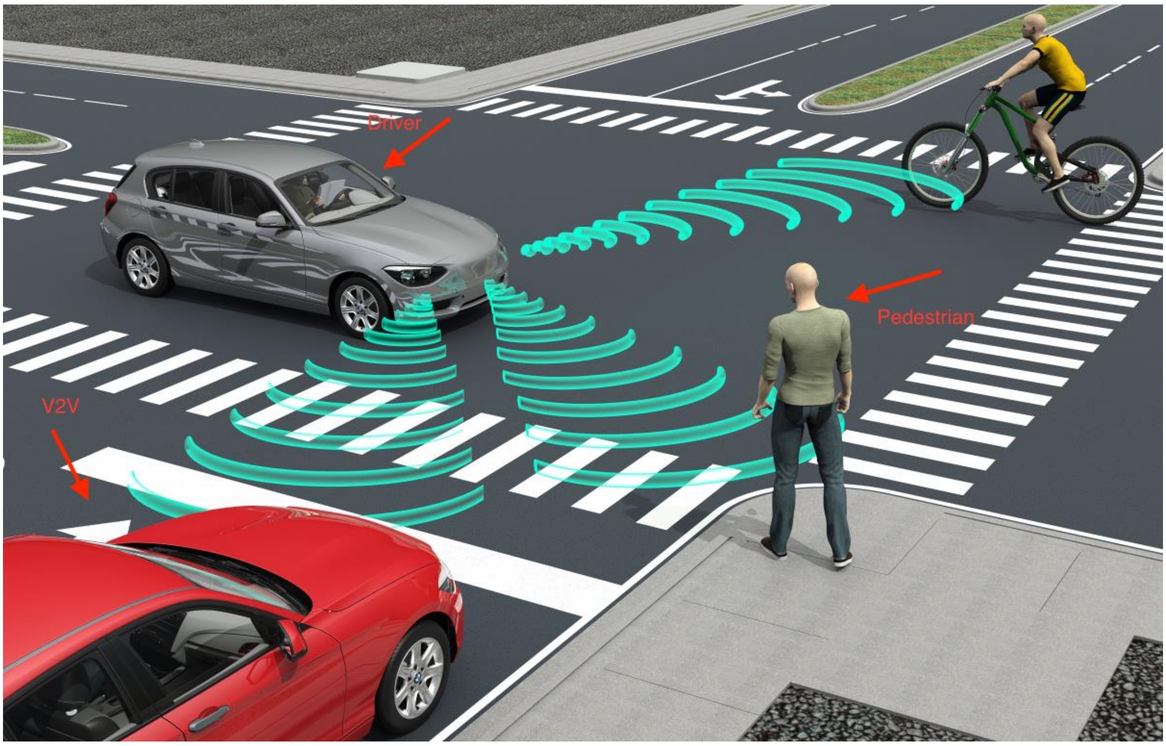

Figure 1: Interaction between AVs and pedestrian, AVs and driver, Vehicles to Vehicles (photo extracted from [13])

The remainder of this paper is organized as follows: Section 2 reviews the literature on the impact of AVs on pedestrians, communication between the vehicle to vehicle and vehicle to infrastructure, and the role of the driver of the AVs. Section 3 provides conclusions and offers directions for future research.

2. INTRACTION BETWEEN THE AVs AND PEDESRTAINS, VEHICLES, AND DRIVER

This section reviews the literature on the AVs impact AVs have on pedestrians, interaction between the AVs and the other road users, and role of the driver. Section 2.1 explains how the AVs may negatively and positively effect pedestrians. Section 2.2 discusses the importance of vehicles to vehicles and vehicles to infrastructure communication. Section 2.3 describes the role of the driver of the AVs and how it may impact collisions.

2. 1 Interaction between AVs and pedestrians

Evidence reveals that autonomous vehicles are more cautious around pedestrians. Google's autonomous vehicles collision reports indicate that in most accidents the vehicles are hit from behind because Google's cars stop to give the right-of-way to the pedestrians [14]. Millard-Ball [15] analyzed the interaction between the pedestrians and autonomous vehicles focusing on yielding at crosswalks using game theory. Autonomous vehicles are programmed to respect the right-of-way of pedestrians, which is conditional on AVs "playing nice." Hulse *et al.* [16] surveyed almost 1,000 participants to assess their perceptions on safety and acceptance of AVs. The results indicate that pedestrians believe AVs are less risky compared to human-operated cars. Moreover, gender, age, and risk-taking personality play an important role in AV acceptance. For example, females were less comfortable with AVs than males and young adults.

In the case of level 5 of AVs, walking could become more pleasant because on-street parking is anticipated to disappear, since driving will become a service and parking move to the suburbs. Moreover, crossing the street should be more convenient, since the AVs must stop for pedestrians and cannot claim that they did not see a pedestrian or drive under the influence of alcohol. Meeder *et al.* [17] discussed the impact of AVs on pedestrian activity. They identified the potential positive impacts of AVs on the pedestrians, i.e., AVs shows higher success rate in detecting the pedestrians compare to human-operated cars. Therefore, walking could be safer and more attractive for pedestrians, since they could cross the street with greater confidence. Furthermore, car pollution will decrease since most of the AVs are expected to be electric. Therefore, the quality of air will improve, the noise level will decrease, and the environment would become even more pleasant for pedestrians. Moreover, more space is available for the pedestrians since the size of the AVs are smaller and they can drive within narrower lanes. It is also anticipated that car sharing will be widespread.

Other researchers have mentioned the negative impacts of AVs on pedestrians. For example, Meeder *et al.* [17] discussed potential abuse of AVs by pedestrians who could make them stop at every location, which would increase congestion, and the pedestrians would have to take the longer paths as they would likely be banned from not cutting through the AVs' roadways at every location. More importantly, communication between AVs and pedestrians is different, thus, pedestrians would need to learn new rules, which they may resist. If AVs are more convenient, their use for short trips may be preferred instead of walking, which will increase congestion and degrade the pedestrian experience. Cities will be probably more organized, and it is unclear how attractive the city center will be to different types of business. Furthermore, a driver's license may no longer be needed and even children could have their own private car. As a result, the number of autonomous cars may increase rapidly, and walking areas may be dominated by AVs.

In contradiction to those who believe that AVs will be more cautious and accurate around pedestrians, others believe that AVs are more likely to be the cause of a crash. Of course, the debate is ongoing. In this regard, one of the central concerns is that AVs are not able to distinguish between different types of objects they encounter with sufficient accuracy, which may threaten the life of pedestrians and lead to incidents with serious consequences. Additionally, at this stage of automation and the current conditions of the roads and traffic signs, AVs are susceptible to be adversely affected by pedestrians such that some people such as a gang could simply stand in front of an AV or attack the car, in order to steal it. In this case, security cameras on the cars with the ability to communicate with a police station would be beneficial. Moreover, the physical design of an urban area needs to be remodeled, in order to control the interaction between pedestrians and AVs to some extent, which may increase the complexity of street design and create subsequent problems. In such case, individuals will have to learn the new traffic signs and rules that requires time and impact transportation safety.

2.2 Interaction between AVs and other users of the transportation network

AV communication with the other parts of the transportation network such as human-driving cars and bicycles is imperative, requiring further consideration. Radio signals are utilized for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. In V2V technology, the wireless communication is employed by AVs to constantly share information such as their location, speed, and intention to turn. Moreover, it allows AVs to sense their environment and maneuver properly to prevent collisions [18]. Hobert *et al.* [19] explained and analyzed the different cases of V2V communication and identified the requirements for safe and efficient operations. Aria *et al.* [20] simulated different scenarios consisting of a 100% Automated vehicles (AV) and 100% conventional vehicles (CV), investigating the impact of AVs on driver's behavior and traffic performance. Their results suggested the positive effect of AVs to reduce congestion, especially during the peak hours; however, since driving AVs does not require too much attention, it may result in driver drowsiness and inattentiveness in the long run due to its tedious nature.

Llatser *et al.* [21] evaluated Inter-Vehicle Communication (IVC) and analyzed the relation between the frequency of the message passing (e.g., information about the neighboring vehicles and their intention) and communication performance. They showed that the frequency of message passing has a direct impact on the maneuvering performance i.e., high message passing frequency results in some data loss, while low frequency leads to use of obsolete data. Utilizing V2V communication systems plays a significant role in AV's lane-keeping and obstacle-avoidance [22]. Zhu and Zhang [23] proposed a simulation-based model to analyze the mixed traffic flow of human-driving and AVs. They considered six different scenarios starting from the situation where all the vehicles are human-driving to the case where all the vehicles are autonomous and concluded that there is a critical point on the density-flux curve that distinguishes two opposite behaviors for mixed traffic flow before and after that point.

Temel *et al.* [24] used orthogonal frequency division multiplexing (OFDM) techniques to analyze the characteristics of the wireless channel prior to and during a crash in order to investigate the vehicle to roadside barrier communication to enhance transportation safety. They presented real-world crash result and emphasized the importance of the antenna height and directivity on the characteristics of vehicle-to-barrier (V2B) channels. Sukuvaara and Nurmi [25] presented suggestions for the V2V and V2I communication to improve traffic safety and smoothness by considering a wireless traffic service platform based on simulations, pilot testing, and analysis.

To make AV a reality, synergy between AVs and other road users and understanding their intentions is essential. It is critical that AVs being able to communicate not only with other AVs but also with the human-driving cars. Obviously, the AVs of a particular manufacturer would be able to interact with each other because they all use the same technology and program for communication. However, there is a high risk of incompatibility between AVs produced by different manufacturers that should be taken into consideration. For example, a Google car could cut off a Tesla car or not recognize the intention of turn, which may result in a collision or other safety related incident. Consequently, the traffic congestion would increase. Moreover, communication between the AVs and other road users is based on the information received by AVs, which can be inaccurate, misinterpreted or even lost.

2.3 Interaction between AVs and driver

One of the critical deficiencies in AVs is the driver's susceptibility to erroneous or delayed decision-making following an alarm from the car, similar to those observed in the aviation industry. In order to avoid undesirable consequences, this process of decision-making and taking the appropriate action should usually take place in a very short time window after the alarm goes off. In addition, the frequency of these incidents likely to be orders of magnitude greater than the aviation industry, given the number of cars on the road relative to the number of planes in the sky. This process of recovering after AV's inability to continue to operate can be impaired by a myriad of factors such as the driver being distracted (taking a nap, talking with other passengers, reading, etc.,) or being unconscious of type of failure such as a malfunction in the speed control system.

In automated driving, the driver may be deeply engaged in other activities, thus bringing a distracted driver back into the control loop can become very challenging. In fact, transitions between the human and automated driving is a key design issue for autonomous vehicles. Merat *et al.* [26] employed a driving simulator to investigate the ability of drivers to handle conditions where automation reverts to manual control, which was based on the length of the time the driver was not looking at the road ahead. They considered eye movement patterns and showed that drivers exhibited the best performance when the control transferred after six seconds after a take-over request. Moreover, they discussed the importance of designing effective human machine interfaces in automated driving conditions, which certify the time and manner in which the message regarding transfer to the manual control is issued. Another imperative factor is how to warn the driver, for example, the necessity of clear language [27] to unambiguously communicate the level of urgency to the driver. Politis *et al.* [28] considered a language-based warning model to switch from autonomous to manual control. They evaluated the audio, tactile, and visual warnings and concluded that it is critical for the driver to intuitively understand the level of urgency.

From a human factors perspective, the crucial challenges are designing automation in a way that drivers fully understand the functionalities, capabilities and limitations of the vehicle, and how to keep the driver engaged to maintain situational awareness of what the vehicle is doing and when manual intervention is needed. Cunningham and Regan [29] reviewed some of the human factors challenges in this regard including driver inattention and distraction, skill degradation, and motion sickness. Petermeijer *et al.* [30] reviewed the literature on vibro-tactile displays as a possible method to alert the driver at the time of transition from automated to manual driving. Four dimensions were considered, including frequency, amplitude, location, and timing. Although vibrotactile feedback has benefits, it also has several limitations such as differences in the response threshold of individuals to receive notice and duration or intensity of vibration that may be uncomfortable. Lu *et al.* [31] proposed a theoretical framework and investigated the human factors in transition from automated to manual driving by defining different joint driving states of driver and vehicle. Kyriakidis *et al.* [32] interviewed 12 expert researchers in the field of human factors and discussed the role of human factors in AVs. They identified the commonalities and perspectives regarding human factors. It was recommended that drivers be trained to be aware of AV limitation to ensure they are capable of operating AVs and maintain control of the car in case of transition from autonomous to the manual driving.

Clark *et al.* [33] analyzed the impact of level of distraction with respect to the age of drivers when predicting the performance of taking control of a highly automated vehicle. They showed that younger drivers were more easily distracted than older drivers. Moreover, age and speed were negatively correlated with high speed among younger drivers. However, their study had some limitations, such as small sample size and the type of activities that participants were engaged in to achieve different level of distraction, which may have resulted in limitations to the generalizability of results. Vogelpohl *et al.* [34] studied the behavior of distracted drivers as they reacted to the unexpected traffic events. Their results indicated most participants reacted to the unexpected conditions and deactivated the automation after seven to eight seconds. Moreover, drivers of the automated vehicles exhibited a delay, up to five additional seconds before the first gaze into the mirror and road in comparison with the drivers of the manual cars.

Another significant factor that needs to be considered is the driver's driving skills. It is critical that driver be able to respond in case of automation failure. Lack of driving skills can be serious and may threaten the life of pedestrians, drivers, and passengers of an AV, although some other factors such as gender, age, level of consciousness are also important.

As discussed, operating an AV will allow the driver to be easily distracted. Therefore, the time to recognize AV failure and resume manual control will increase. One solution is to use eye detection technology that can track the driver's eyes and alert the driver when the driver is not focused enough. Since reaction time plays a critical role in case of automation failure, it would also be valuable if AVs could predict when something might go wrong and alert in advance.

3. CONCLUSION

This paper considers three categories of AV interactions including: I) pedestrian, II) vehicle to vehicle/infrastructure, and III) drivers and passengers. The recently published papers in this area were reviewed and the gaps requiring additional focus were identified. Most studies assume AVs will play nice. Although this assumption simplifies the experiments, AVs experience failures, which create unforeseen problems. More studies regarding interaction with pedestrians are needed to develop methodologies and algorithms so that AVs can make robust decisions on what action or sequences of actions would mitigate consequences when confronted with challenging situations. Moreover, current transportation network is not designed for AVs. Therefore, AV interactions with pedestrians have not been considered in the process of their design. For vehicle-to-vehicle and vehicle-to-infrastructure category, communication between AVs of different companies requires standards and protocols to be compatible, so that they can share information and intentions with each other to reduce the risk of collision. Moreover, interaction between AVs and human-driven cars need to be investigated for the same purpose. In both cases, the reliability of the information being transferred between vehicles needs to be assured, since inaccuracy in the data transferred could result in an incident. A final category is the interaction between an AV and drivers and passengers of that AV. The driving skills and possible loss of situation awareness of the driver need to be studied thoroughly to increase the reliability of AVs. For example, a driver with low or degraded skills from lack practice, may perform an incorrect action in a situation that could lead to a collision. Moreover, since driving an AV may be a monotonous task, the driver may become easily distracted by other activities making them more prone to taking inappropriate actions when human intervention is required.

Future work will expand this work and consider the impact of AVs on pedestrians, drivers, infrastructure and other users of the road. More specifically, we will discuss the possible failures in greater detail and will offer potential solution and methods to objectively measure efforts to make improvements that enhance safety and convenience.

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