Literature Review of Safety and Humanity in Autonomous Vehicles

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Abstract

The goal of this research paper is to evaluate recent safety and user experience research in the field of autonomous vehicles (AV). According to researchers in [1], when autonomous vehicles are able to chauffeur drivers and passengers safely and comfortably, 'humanity' is being considered by the AV system. The theoretical framework proposed by researchers in [6] can help guide researchers interested in AV research understand how technical modifications in data and network can be leveraged to affect AV systems in making theoretically better decisions, with the primary objective of safety and humanity in mind.

It is useful to understand the features and specific signals used by AV software in the form of data, as is mentioned in [2, 3], when conducting research that studies the user experience of AV's, such as in [5]. These papers [2, 3] detail the Extraction, Transformation, and Loading (ETL) process (prior to being used within an artificially intelligent or machine learning network) on the same set of data for different purposes. Similarly, researchers in [4, 8, 9, 10] describe underlying network systems. Different networks process the data differently, so it is up to system architects to identify and promulgate positive and mitigate negative aspects or behaviors of this technology.

Given a general idea of the structure of the data and systems used in AVs, it is convenient to take a look at the performance of the system to make evaluations. There are two papers related to categorizing and testing such systems that were analyzed [3,4]. Firstly, on how simulations of AV's may impact emissions [3] in mixed non-AV traffic. Secondly, the ability of AV systems to detect multiple Vulnerable Road User (VRU) populations, specifically E-Scooter drivers [4].

Recent AV's may have not yet reached the level of maturity to be considered a fully autonomous vehicle, or they limit more functional software to customers who can afford it. There may be a variety of reasons for why these systems are not fully capable, and this research project aims to recognize how current systems monitor the safety of drivers while enhancing the driving experience.

This research project considers the SAE (Society of Automotive Engineers) automation levels commonly used when categorizing AV's as mentioned in [1, 6] to determine the gap when making improvements to the system.
Future researchers that propose new technologies, such as in [7], could utilize this knowledge for applying changes to these systems that improve the safety and 'humanity' of AV's.

1. Introduction

AV technology has become a trending feature of newly released vehicles. Stakeholder's in the technology may be interested in the level of safety and benefits to the user's driving experience.The level of safety of their vehicles ADS (Autonomous Driving System) gives insight into whether you will sustain less accidents on the road. Similarly, the benefits to the user's driving experience may improve comfortability and mental wellbeing.

However, currently most AV's on the road are currently level 2, where the functionality of AVs is not at the level of fully autonomous for certain users, as mentioned in a news article citing an english research study [11]. Level 2 vehicles are an example of limited self-driving. This experience of AV driving is to offer limited autonomy to the car, and warn drivers when human attention is required. Given the scope of this literature review, understanding the level of autonomy for a particular AV is helpful for assessing the vehicle's safety and user experience.

The general public and even many novice researchers may be unaware of the AV taxonomy, popularized by the SAE and referenced by much of the research reviewed in this paper [1, 5, 6, 11]. Thus it may be surprising to find that researchers in [6] believe aspects of their taxonomy had been misinterpreted by previous researchers, and proposed expanding the taxonomy to consider classes of AVs offering semi or mixed autonomy. Despite some researchers extending the SAE JS3016 taxonomy specifically, the original taxonomy is still quite popular, as exemplified by researchers in [1] that have conducted a study to evaluate the safety and user experience of 'SAE Automation Level 2 cars'.

It is interesting however to note that AV's with a higher SAE automation level may or may not exist or have been tested for their safety and user experience. Thus future research may consider the possibility that cars with a higher level of autonomy might offer mixed-autonomy as well and allow for user's to take primary control of the vehicle, increasing the complexity of the overall system.

2. Background

Previous works in the field of AV's range in topics from very low level and technical to very high level and theoretical. Of the many fundamental topics that may be considered, the topics of safety and human experience of the automatic driving system are exceedingly important when designing AV systems that value 'humanity', as is mentioned by research in [1]. These two topics together strike a balance that future AV research should value when proposing new technology. As novel AV systems can be tested either in-silico (i.e within a computer simulation, using AR/VR or other technology) as in the study by [5], or in-vivo (i.e within a real-world vehicle test drive) as in the study by [1] - rigorous testing is a must-have before release of new software to production settings.

2.1 Safety

When driving an AV, it is a safe assumption to believe that your ADS is capable of triggering the car to break and stop when faced with a potential collision, without requiring the driver. For this purpose, much progress has been made on algorithms and networks in [4, 8, 9, 10] using images and videos to detect cars and pedestrians (aka. VRUs or Vulnerable Road Users). However, this functionality may behave differently depending on the level of autonomy of the vehicle [6].

Table 1. Availability Patterns and Sequence of the Concepts.

Day	Availability of ADS			Concept	
	Highway Segment 1	Highway Segment 2	Highway Segment 3	Group 1	Group 2
Monday	Available	Not available	Not available		
Tuesday	Available	Not available	Not available		
Wednesday	Not available	Not available	Available	CA	Not CA
Thursday	Available	Not available	Not available		
Friday	Not available	Not available	Available	Not CA	CA

CA = context-adaptive.

Figure 1: A table in [5] modeling an ADS that is unable to activate autonomous driving on certain road conditions.

A secondary safety concern involved with driving is fuel emissions. Data can help us paint a picture regarding the behavioral reactions that AVs may induce in non-AV drivers and vice-versa. The potential for more fuel-efficient driving resulting from increasing numbers of AVs on the road is studied. For example, in [2] an open-source AV dataset called the Waymo Open Dataset was processed and analyzed.This same dataset was used in generating in-silico simulations of traffic emissions in [3] to understand how the adoption of AV's will affect the environment. Arguably, this can improve safety by having a positive impact on respiratory health.

2.2 Humanity and User Experience

In testing the 'humanity', or the ability of autonomous vehicles (AV) to drive indistinguishably from human-driven vehicles, researchers in [1] assume that a car with 'humanity' will cause the drivers to exhibit less (or, no) risky behavioral changes that lead to problematic driving. As 'humanity' in AV's implies an equal (or better) level of safety than human drivers, it is necessary as a public safety precaution to study how current systems acknowledge human behavior and utilize this data with respect to safety while enhancing their driving experience.

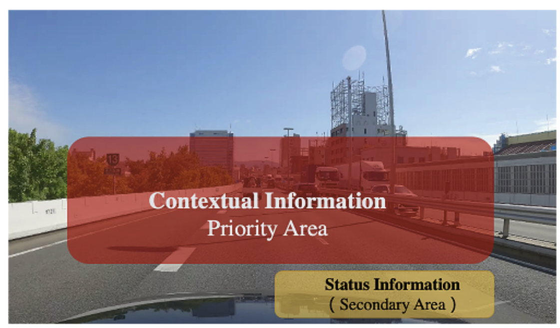

Fig. 3. Layout of AR-HUD interface

Figure 2: An image in [7] displaying a potential human-machine interface presented on the windshield.

It is thus beneficial to investigate the effect of common and future AV user interfaces (UI) on human behavior to improve the AV's consideration of 'humanity'. For example, researchers in [5, 7] have studied user interfaces that utilize the drivers behavioral patterns to improve user experiences.

3. Review Methodology

Approximately 4 weeks were allocated to collecting current research. Ultimately, 10 articles were included in this review. The majority of the articles were published in 2022. These articles vary by theme or topic, and preference was given to articles that covered safety or user experience in AV technology.

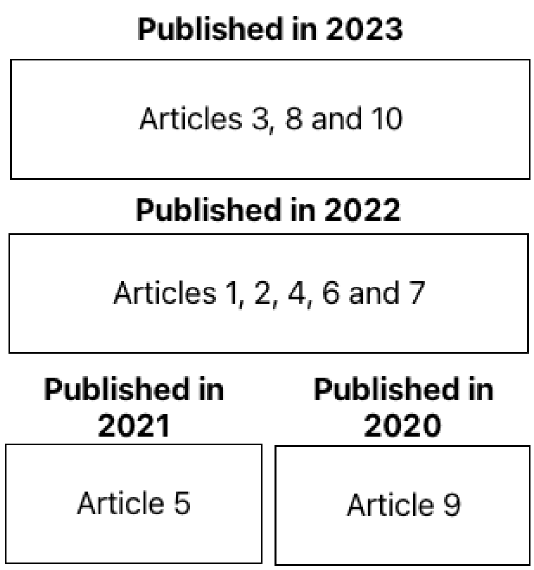

Figure 3: A diagram of the selected paper's publication dates.

4. Thematic Synthesis

In this section, summaries of the findings are categorized by theme and are evaluated relative to safety and user experience. The findings are categorized according to the themes of 'Current and Theoretical Approaches to Designing AV Systems', 'Image to Video Monocular 3D Object Detection in AVs', and 'Behavioral Studies of User Experience of AVs'. For example, papers that covered current and potential future UI design in AVs were reviewed. Similarly, many covered machine learning algorithms using images or video for object detection in driving scenarios. Lastly, papers that detailed in-silico and in-vivo behavioral studies of current and potential future user experiences were also included in the review.

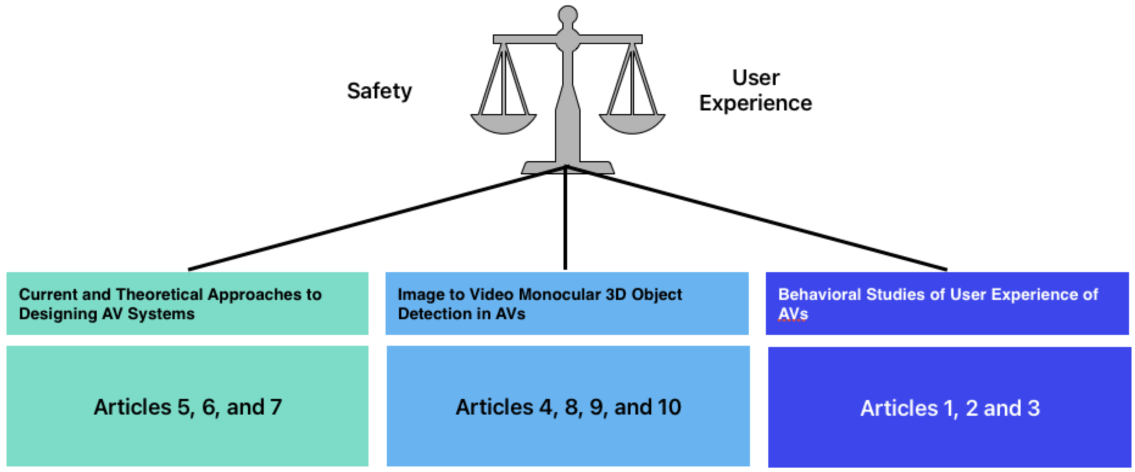

Figure 4: A diagram of the thematic synthesis and review method. The papers are categorized by theme and evaluated on contribution to safety and user experience.

4.1 Current and Theoretical Approaches to Designing AV Systems

Research in [5, 6, 7] is primarily concerned with 2 topics within the field of AV's: research of current and potential future user experience as in [5, 7] and theoretical research for how AV systems develop, as in [6]. Researchers in [5] studied the current method of notifying users of their ADS' availability to activate on current road conditions. They tested their theory using car driving simulation with real users and found that providing text in the Human-Machine Interface (HMI) - that was in the form of the on-board tablet - when the self-driving feature was not available actually *increased* distraction due to increased gaze frequency away from the road, and that a static non-availability icon resulted in less distraction. However, text improved reaction times when the driving function was available.

While researchers in [5] considered current methods and experimented with slight modifications to the HMI, researchers in [7] considered not-yet-released methods of presenting the HMI by experimenting with how advancements in UI technology would affect the HMI. They theorized that future AV's will be able to present drivers with a HMI (Human Machine Interface) in the form of an AR (Augmented Reality) HUD (Heads-up Display) within their vehicle's windshield or direct field of view. The authors suggest that an AR HUD should only present information that is crucial to prevent increasing cognitive load and distractions. Thus, they created a mock-up of the layout of a HUD and tested the types of information that would be pertinent for drivers based on driving experience and road environment conditions.

The authors in [5] found that beginner driver's tend to have a statistically significant difference in information requirements based on the driving environment given a specific driving action.

For skilled drivers, the authors found that they did not require different information based on the driving environment given a specific driving action. However, the authors note that both beginner and skilled drivers place a priority on direction visualization when following a predefined route.

While also focused on safety and user experience, [6] is instead a theoretical research paper where the authors proposed improving the user experience by crafting new 'design spaces' having defined abstract objectives and concrete functionalities of the AV. The design spaces model the relationships between the objectives and the functionalities and potential cascading changes that may arise due to a switch in the driving agent. As the 'design spaces' consider both safety and user experiences and other potential use-cases, these 'design spaces' could then be used to evaluate vehicles having multiple or mixed levels of SAE automation and variable user experiences in fulfilling the primary objectives of a driving task. This study was thus able to infer based on a user's prior driving experience the level of information to present within a UI or HMI.

4.2 Image to Video Monocular 3D Object Detection in AVs

Researchers in the paper [4] present an enhanced E-Scooter rider detection model. This model is based on monocular imaging as input to the network. They contrast their model's performance to other 'state of the art' models on their ability to detect types of objects such as cars and 'Vulnerable Road User' (VRU) categories such as cyclists and pedestrians. Two contributions of the author's research are a novel E-Scooter rider benchmark dataset that is able to classify detection models based on their detection ability, as well as a new occlusion-aware method that is shown to improve the detection of partially-occluded E-Scooter drivers by ~16% over current SOTA methods. Their model utilizes images as input to their model.

While also using images as input, researchers in [8, 10] also studied monocular 3D object detection algorithms for AVs. They studied the ability of their models to capture further information related to the 3D environment forms from images as input to the network. Researcher's in [8] claim that Pseudo-LIDAR and stereo-vision based object detection technologies are prior technologies for autonomous vehicles, despite monocular object detection technologies being more cost-effective and having potential to improve scalability. Thus, the researchers in [8] states their main research problem was to introduce a new method that is based on monocular object detection technology and solves the problem of losing depth perception caused by using this cost-effective technology. They achieved a SOTA method in 'monocular 3D pose and shape reconstruction' of traffic scenes via an algorithm known as 'bi-contextual attention and attention-guided modeling' also known as BAAM.

The research problem stated in [8] is similar to the one posed in [10], while both papers were also published in the same year. The techniques used though are quite different. In [10], the authors propose a new method to "improve the accuracy of detection of objects with large differences in deformation [...] when in motion" when using monocular imaging. The researchers' problem statement is improving detection of 'non-rigid' objects like bicycles as opposed to rigid objects such as cars. Despite their problem statement considering the movement of objects, their work was evaluated using static images for object detection.

The authors in [10] found that the number of 'keypoints' (or, the number of sampled images used for each class of object when training the object detector) varies by object. This finding relates to their earlier hypothesis that rigid objects such as cars are easier to detect than non-rigid objects like cyclists. Cyclists thus require more keypoints than cars, and their findings confirm this. The results of their model also showed they were able to improve the detectability and accuracy of their model on the cyclist category over other state of the art models.

Although [8, 10] were not evaluated on video of live traffic scenes where images of objects in motion were used as input to the object detection networks, research in [9] was. The authors' purpose in [9] for researching video-based monocular 3D object detection techniques is that current progressive studies in object detection using monocular cameras primarily used images. The authors addressed the issue where techniques based on images did not perform well in video settings. They proposed 'a novel decomposition of object orientation and a self-balancing 3D confidence' using a model that had achieved improved accuracy in localization of objects on birds-eye-view tasks within the KITTI self-driving dataset.

4.3 Behavioral Studies of User Experience of AVs

In papers [1,3] both study the difference in behavior of AV driver-agents versus non AV drivers, whether it be on safety and acceptability or environmental effects respectively. In papers [2, 3], on the other hand, both study the same underlying dataset that is used to guide the AV system. Research in [2] is focused primarily on processing and evaluating the data, while [3] is focused on the effect of AV's on driving behavior via emissions. Notably, researchers in [3] cover both topics of processing and evaluating the data as well as studying the behavior of AVs compared to non-AV's. There is, however, a major difference between how [1] and [3] study AVs vs non-AVs; research in [1] is conducted in a real-life driving scenario with actual AVs and driving agents, whereas research in [3] is conducted in a simulated scenario where the emission rates and car following patterns are simulated according to the Waymo Open dataset.

The research in [1] found that the participants were able to detect, with a statistically significant p-value, the difference between human and automation agent when experiencing moderate lane keeping at any speed above 80 km/h, and moderate braking at speeds above 100 km/h, both in high traffic congestion. The authors theorize this is due to the AV's speed in heavy traffic causing a sense of fear that allows the participants to detect the driving agent at a greater sensitivity.

Also on the topic of driving behavior, researchers in [3] found that the arrangement of the vehicles on the road have a significant impact on the driving behavior of AV's, and that this will in turn impact emissions. The researchers claimed that 'the largest environmental benefits were found when an AV is in the lead position' and that it was observed that when an AV is following a HV (Human Vehicle), the AV's drive more 'conservatively' which impacts the time gap and acceleration of the AV that have the effect of higher emissions.

As the study in [3] was implemented using simulations based on data, whereas [1] was not, the results in [1] may be more prone to errors in data collection or processing. For example, [2] studies the same open-source AV (Autonomous Vehicle) dataset called the Waymo Open Dataset used in [1]. Their goal is to study features in the dataset utilized for 'car following paired trajectories'. The authors claim in their conclusion that they were able to conduct extraction of the Waymo Open Dataset and transformed and engineered new data features into a "user-friendly tabular format".

They mention that the results of their consistency analysis "show that the data itself is not internally consistent". Furthermore, the results of their jerk analysis showed "a large proportion of anomalies exist in the position-based data", with a smaller but still significant amount also present in the speed-based data.

4.4 Discussion of Safety and Humanity

In this section, the gaps and limitations in the collected research will be discussed briefly with subjectivity and the author's own opinion. At the outset of this literature review, it was stated that safety and human experience were primary objectives to be considered when evaluating current research on the topic of autonomous vehicles. Thus this section will elaborate on how the papers in each category contributed to these objectives.

Current and Theoretical Approaches to Designing AV Systems

User interface research in vehicles has the potential to affect all vehicles, and not just autonomous ones. While research on the ADS UI via availability notifications in [5] is specific to autonomous vehicles, emerging research on the AR HUD as in [7] has wide applicability. Notably, these two technologies have the opportunity to combine their strengths to improve the user experience and reduce distractions caused by using an in-vehicle tablet for presenting the HMI. Furthermore, the research in [5] studies the HMI and user experience of level 3 SAE AV's, a frontier in AV technology.
It assumes level 3 SAE AV's will offer drivers greater freedom in their ability to complete NDRA's (non-driving related activities) while driving that remove the driver's attention from the road and considers the safety of the system as well as user experience. Future work may also benefit from defining abstract safety and user experience objective 'design spaces' as proposed in [6].

Image to Video Monocular 3D Object Detection in AVs

Understanding the underlying machine learning network architecture is critical in evaluating the safety of the system. The research in [4, 8, 9, 10] all contributed to advancing the abilities of networks, with a primary focus on improving detectability of humans or VRU's outside of the vehicle, as opposed to cars. Although safety in this case is measured by the performance of the network at detecting objects, future work implementing these networks would take the detected objects into account by using the results of the networks to influence decision-making within the ADS to initiate movements that avoid collision.

This work may also directly impact the user experience by improving the mental well-being of AV drivers and passengers. This can be a result of experiencing less collisions, or being unable to detect the shift from the human to the autonomous driving agent in the midst of traffic.

Behavioral Studies of User Experience of AVs

The collected behavioral studies of user experience covered the topics of 'humanity' by estimating whether driver's in the AV vehicle were able to detect if the driver is a human or not [1], as well as the effect of mixed-autonomy vehicles on the environment via gas emissions [3]. These two topics both contribute to safety. For example, the work done in [1] hoped to understand the detectability of the ADS with a lower detectability signaling that the ADS is driving with equal (or better) driving ability than a human would. A lower detectability may cause AV's to experience greater acceptability by non-AV drivers on the road. Similarly, the work done in [3] sought to forecast the gas emissions in traffic of non-AV's with or without AV's following or leading. This can impact safety by influencing public health due to the negative effect gas emissions have on the environment.

5. Conclusion

This literature review covers ten relatively recent research papers in the field of autonomous vehicles. The themes explored within this review attempted to cover a wide range of topics within this field to convey a holistic understanding of the topic. While only a limited number of articles were collected, the general insights are valuable and may be useful in future work seeking to further improve safety and user experiences in AVs.

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Appendix

Table 1. Availability Patterns and Sequence of the Concepts.

Day	Availability of ADS			Concept	
	Highway Segment 1	Highway Segment 2	Highway Segment 3	Group 1	Group 2
Monday	Available	Not available	Not available		
Tuesday	Available	Not available	Not available		
Wednesday	Not available	Not available	Available	CA	Not CA
Thursday	Available	Not available	Not available		
Friday	Not available	Not available	Available	Not CA	CA

CA = context-adaptive.

Figure 1: A table in [5] modeling an ADS that is unable to activate autonomous driving on certain road conditions.

Fig. 3. Layout of AR-HUD interface

Figure 2: An image in [7] displaying a potential human-machine interface presented on the windshield.

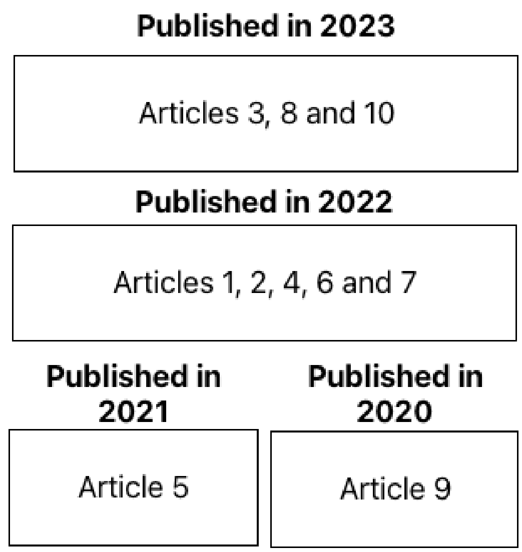

Figure 3: A diagram of the selected paper's publication dates.

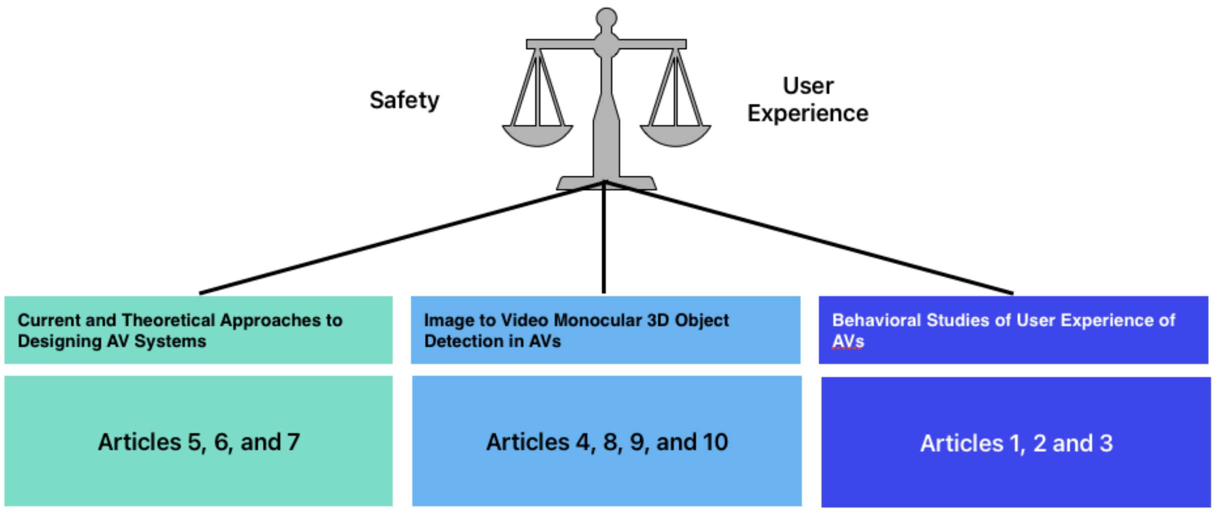

Figure 4: A diagram of the thematic synthesis and review method. The papers are categorized by theme and evaluated on contribution to safety and user experience.