DETECTION OF ROAD MARKINGS AND ROAD SIGNS BY ADVANCED DRIVER ASSISTANCE SYSTEMS – A LITERATURE REVIEW

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Abstract

Modern vehicles are equipped with active and passive safety systems that can mitigate the severity of crashes or even prevent them. The most popular active systems in vehicles are Advanced Driver Assistance Systems (ADAS), which help the driver operate the vehicle safely. The proper functioning of ADAS is highly dependent on the accurate collection of information from the surrounding environment. Some of the important information can be found in road markings and road signs. In general, road markings and signs are elements of road infrastructure that guide drivers and provide them with the necessary information about road features and the traffic situation. Nowadays, with the widespread use of ADAS, beside human drivers, road markings and signs should also efficiently provide information to perception sensors in vehicles, such as cameras and LiDARs. Due to the technical characteristics of sensors, system malfunctions can sometimes occur due to internal factors or misinterpret events in the vehicle environment. The main problems in detection are related to road characteristics (e.g., quality of marking and horizontal alignment) and environmental factors (e.g., weather conditions). The aim of this paper is to provide a systematic review of the existing literature and findings on the factors that influence the proper detection of road markings and signs by ADAS.

Keywords: ADAS, road markings, road signs, perception sensors, detection, literature review

1 Introduction

According to the newest statistics from the World Health Organization (WHO), approximately 1.19 million people die each year as a result of road crashes [1]. To address this issue, proactive measures have been implemented, such as the European Commission's "Safe System" Approach, which emphasizes the prevention of crashes by accommodating human errors [2]. As humans are inherently prone to error, it was assumed for many years that they were the main cause of crashes and that about 85% of all crashes were caused due to human error, but factors like road and vehicle conditions also contribute [1]. The Safe System Approach is focused on the five pillars of road safety: 1) Safe speeds; 2) Safe infrastructure; 3) Safe vehicles; 4) Safe road user behaviour and 5) High-quality post-crash care [2]. Vehicle safety systems have notably improved over the past two decades, with passive systems reducing crash injuries and active systems aiding in vehicle control [3]. One of the main active systems are ADAS which performs various tasks and support the driver while driving with the assistance of cameras, RADARs, LiDARs and other sensors that recognise the static and dynamic content of the vehicle's surroundings. Some ADAS use sensor fusion, which combines data from multiple sensors to provide more accurate detection of the environment around the vehicle [4].

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Since July 2022, all new models of vehicles in the European Union must be equipped with some form of ADAS systems. This requirement will be extended to all new vehicles from July 2024 onward [5]. Road signs and road markings play a crucial role in the road infrastructure, guiding and giving important information to human drivers about the road ahead. With the implementation of ADAS in vehicles, the aforementioned elements now interact not only with the drivers but also with the vehicle, i.e., sensors in the vehicles. Systems like Traffic Sign Recognition System (TSRS) and Lane Keeping Assistance (LKA) rely on accurate sensor detection of road signs or road markings. The detection of road markings within the LKA system is primarily used to notify the driver about leaving the traffic lane and assist in keeping the vehicle within the lane. Those features in vehicles have an important role in decreasing the number of road crashes, given that in Croatia in 2021, a considerable number of crashes (31.8%) of all fatal crashes resulted from vehicles deviating from the road [6]. Because of the complex technical characteristics of sensors, they sometimes experience system malfunction due to internal factors or misinterpret events from vehicle surroundings because of road characteristics and environmental factors [7]. This paper shows a literature review of previous research on factors that influence on recognising road signs and road markings with the ADAS.

2 Literature review

Implementing ADAS in vehicles is a promising proactive measure for decreasing the number of road crashes. However, sensors used in ADAS vehicles depend on the accurate collection of information around the vehicle. In the following chapters, some of the main problems and factors that affect systems for the recognition of road signs and road markings are described.

2.1 Factors that affect the recognition of road signs by ADAS

The Traffic Sign Recognition System (TSRS) relies on previously mentioned on-board sensors, which capture images while driving. The data collected by sensors is analysed using processing circuitry. TSRS uses algorithms to identify and analyse information from images of road signs. The results are then compared with external databases and road signs are recognised on the basis of attributes such as shape, colour or special features that are unique to each road sign. A bounding box is drawn around each potential road sign, demarcating it as a region of interest [8]. The identified shape of the signage is generated by converting the input from the sensor (mostly the camera) into a binary image, which is then compared to a database of predefined sign shapes [9]. The end result of this complex process is the displayed information of the TSRS output in a clear and readable format for the driver. The existing literature related to the TSRS mainly focuses on the development of new methods and algorithms for the mentioned systems as well as analysing the effectiveness of different algorithms. Most of the work published in the area of road sign recognition separates the detection and classification of road signs as two different problems. The detection of road signs from collected outdoor images is the most complex part of a road sign recognition system and Fig. 1 shows some common challenges for TSRS.

Figure 1 Examples of some of TSRS challenges - occlusion, damaged sign, faded sign with graphic changes

Such challenges can have an influence on the clarity of detected road signs, thus making it more complicated for algorithms to process and recognize them. Lopez et al. (2017) highlighted that the intensity of the colours on the signs is crucial for the accuracy of the TSRS [10] and consequently faded or damaged signs are a major challenge [11]. A Study by Temel et al. (2020) shows that decolorization resulted in 63% performance degradation. In addition, they concluded that the size of road signs has no significant effect on the accuracy of TSRS [12]. The algorithms usually perform comparisons within predefined dimensions, and sign data in the form of images can be scaled up or down to match the sample signs in the database. One common mistake is position of the camera inside the vehicle. Namely, camera should be placed in a way that is pointing towards the same direction as the vehicle, i.e. orthogonally to the egomotion direction of the vehicle [13].
Furthermore, graphic changes in road signs can significantly impact TSRS accuracy. An Austroads study from 2018 identified several problems with the recognition of faded, damaged and graffitied road signs [14]. A study from Temel et al. (2020) showed that visual artifacts and exposure affected TSRS and resulted in 80% performance degradation, whereas shadow resulted in least degradation with around 16%. Detection performance degradation based on darkening, noise and blur is between 30% and 48%, whereas dirty lenses exceed 50% [12]. Babic et al. (2021) investigated the accuracy of TSRS in seventeen cars, of which fourteen were from different manufacturers. In order to test accuracy, the test field had road signs with purposefully made graphic changes on them. The results indicate that TSRS accuracy had variations not only among different car brands but also within the same brand. Additionally, the introduction of graphic changes significantly impacted TSRS accuracy across all vehicles when compared to the control condition (without graphical change), with percentages ranging from 62% to 99% [15]. Moreover, inclement weather conditions affect camera and LiDAR detection performance. Temel et al. (2020) found out that snow, haze and rain degrade the performance of the aforementioned sensors up to 48% [12]. Seraj et. al. (2021) investigated the implications of weather and reflectivity variations on TSRS, and found that the impact of reflectivity conditions was far more significant than of weather impacts. The study consisted of a comparison between two sign types: engineer grade with low retroreflectivity and diamond grade with high retroreflectivity, daytime and night-time conditions and sign age. The comparison between different ages of engineer grade signs showed significantly higher levels of recognition of new signs (age ≤ 1 year) as compared to older signs (age ≥ 3 years) and sign recognition was less sensitive to age when using diamond grade sheeting [16]. In addition to graphic changes and weather factors, the presence of other objects in the scene, such as moving cars, bicycles, pedestrians and shop signs can create obstructions in road sign detection [17].

2.2 Factors that affect the recognition of road markings by ADAS

Lane Support Systems (LSS) is a general term for ADAS that utilize lane detection to perform functions such as collision warnings, facilitate automated driving tasks or mitigate potential collisions. Lane Departure Warning (LDW) warns the driver by means of visual, acoustic or tactile feedback when approaching or crossing a lane marking without activating the indicator, while Lane Keeping Assistance (LKA) represents an enhanced iteration of LDW, which is actively steering to keep the vehicle within its lane [9, 13]. Road marking detection mainly consists of finding a certain pattern, such as various lines on the road or colour contrast. Like road sign detection, images from sensors are continuously processed to determine the vehicle's position and alert the driver if they unintentionally leave their lane. However, since they rely on optical detection, their performance may be impacted by external factors [17].
A study by Hadi et al. (2007) showed that the performance of LDW improves with increased road marking retroreflectivity.

In the case of worn-out yellow markings and yellow markings on concrete pavement quality of detection decreases, mainly because of the lower contrast in comparison to white road markings [18]. Similarly, Carlson et al. (2017) concluded that the camera detection of road markings generally improved with a higher retroreflection and contrast ratio. The system generally detected markings with a minimal retroreflectivity of 100 mcd/lx/m2 but does not necessarily provide the strongest detection [19]. A study conducted in 2010 in Sweden, concluded that in dry daytime conditions, luminance coefficient (Qd) must be at least 5 mcd/lx/m2 higher than the road surface and it should be at least 85 mcd/lx/m2 [20]. Furthermore, the results of the study from Babic et. al. (2021) indicate that road marking detection is greater at night-time compared to daytime due to the complexity of visual clutter that decreases the contrast ratio between white marking and the road surface and thus affects the detection quality and view range of machine vision [21]. Although several factors (low-angled sunlight, snow and fog) may affect the detection and readability of machine-vision, majority of studies focused on the impact of rain. Under dry and light rain conditions, machine vision in the majority of cases does not have problems detecting road markings. However, heavy rain at night significantly decreases detection of road markings due to rainwater retention on the markings or because of excessive light reflection from the puddles [18]. In 2020, Roh et al. did a study where they analysed impact of rain conditions on LDW based on the Mobileye 630 camera. The amount of artificial rainfall discharge at the test site was controlled per hour through the artificial rainfall facility. Tested rain levels ranged from 0 mm, 10 mm, 20 mm to 30 mm. Results confirmed that when the rainfall increases, it affected the view range, such that the visibility of the surrounding environment decreases [22]. Furthermore, Burghardt et al. (2023) investigated the visibility of flat lines and structured road markings for machine vision and found that the measured camera contrast ratio dropped in the presence of moisture in the case of flat line markings but remained high in case of structured markings that facilitated moisture drainage [23]. In 2024, Zhao et al. investigated LiDAR response to two types of road markings with different retroreflectivity in dry, wet, moderate, heavy and rainstorm conditions. Type II structured road markings with premium glass beads with a refractive index of 1.65 provided higher LiDAR reliability for road marking recognition systems [24].

In 2021, researchers at the University of Catania investigated how different road characteristics and conditions impact the performance of LKS. They used Automatic Road Analyzer (ARAN) to measure road characteristics (cross section, gradients, horizontal and vertical alignment), a Mobileye camera and a portable retroreflectometer for the detection of luminance coefficient of the road markings in diffuse lightning conditions (Qd). Results showed that the probability of LKS failure rises to 11.4% (calibration sample) and 14.35% (validation sample) when the Qd of road marking is lower than 153 mcd/lx/m2. Furthermore, curved road sections (with R‹141 m) showed a higher percentage of faults than the average 3% in the test conditions [25]. In addition to road geometry, Forst and Lundkvist (2010) found out that roads wider than seven meters must have a center line in order for the lane support system to become active [20]. Furthermore, several studies investigated how an increase in lane marking width from 10 cm to 15 cm influences the detection rate, and it was concluded that there is a positive correlation between the confidence of detection and wider lane marking [26]. The most common road marking detection challenges are shown on Fig. 2: a) different road markings, b) the width of road markings is changed, c) different lane widths, d) high saturation of image at the exit of the tunnel, e) cast shadows on the road, f) road covered with snow, g) low visibility due to fog, h) low visibility due to heavy rain, i) reflections on wet road at night-time [27].

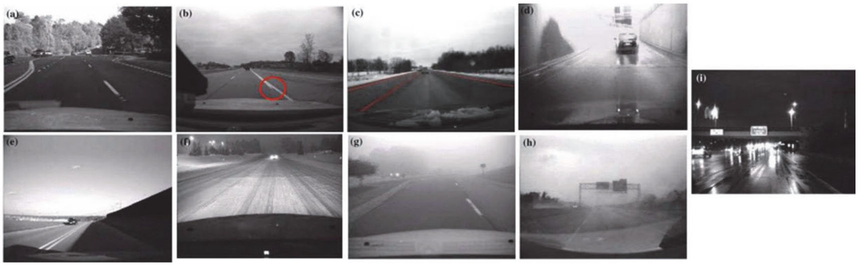

Figure 2 Challenging scenarios for road marking detection systems [27]

3 Discussion and conclusion

Road crashes are represented as one of the primary contributors to global mortality. Considering that, the development of active vehicle safety systems that could prevent road crashes is a global focus, with the ADAS market rapidly growing. Predictions suggests that ADAS, especially the LDW system, could prevent 11 to 23% of drift-out-of-lane crashes and 13% to 22% of serious to fatal injuries to drivers [28]. While the ADAS holds the potential to minimize the occurrence of road crashes [29], it can sometimes, due to certain factors, react unexpectedly or the ADAS reaction could be completely missing. In order to find factors that affect correct detection, recognition and trigger unexpected reactions from ADAS, a large number of training, testing and research on those systems has been conducted in recent times. In terms of the proper functioning of the Traffic Sign Recognition System (TSRS), it is important to pay attention to the condition of road signs, such as their retroreflective values and depending on the road category, use materials with the prescribed values. Moreover, it is crucial that the road sign has no damage that could cause a misinterpretation of its meaning. Graphic changes in road signs significantly influence TSRS accuracy, as well as faded and non-standardized road signs. Factors like car vibration, motion blur, camera orientation in the vehicle and dirty camera lenses further impact image quality. Furthermore, other factors that affect the visibility and legibility of road signs can be design of the signs, visibility, placement, partially hidden or masked signs and the presence of advisory and information signs. In addition, inclement weather, such as rain and snow, are also a contributing factor to poorer recognition of road signs.

The road marking detection process poses several challenges, particularly in adverse environmental conditions such as heavy rain, snow or fog. Those weather conditions can affect the proper detection of road markings by interrupting the sensor signal and producing occlusion in camera detection. Factors like road geometry, changes in pavement colour, continuous or broken lines and shadows on the road contribute to the complexity. Low visibility can be caused by sun glare or lights from other vehicles, which can blind the camera or lower the contrast between road markings and pavement. In addition, rural areas with minimal traffic may lack horizontal markings, which are essential for road marking detection and vehicle path planning. Standardisation issues, varying marking quality and road surface conditions, including cracks and potholes, can lead to misinterpretation.

Machine vision advancements are important for overcoming visual clutter, road conditions, and weather challenges for both TSRS and lane detection systems. Like any technology, further research is necessary to enhance existing sensor technology, train computer vision algorithms and develop improved versions. Moreover, vehicle sensors standardisation will help in the development of sensor fusion in vehicles, which according to some researchers, would be the best solution for accurate detection in case of any road sign anomalies [30]. Various research findings highlight the need for road marking standards and maintenance policies, even more because machine vision, such as cameras can be to a certain extent compared to human vision. Findings from those researches are important for ADAS manufacturers to understand how systems are used and how they behave in many situations on the road. In addition, implementation of high-definition maps with complete database of road signs and road markings could assist in detection.

Overall, road markings and signs must meet regulated standards, considering quality characteristics and dimensions. Current standards, designed for human drivers, may not be fully sufficient for ADAS. To improve road markings visibility for ADAS in vehicles, there should be improvements in their retroreflectivity, line width, contrast ratio clarity and unification. Research suggest that a minimum retroreflectivity level of road markings in night visibility should not drop below 100 mcd/lx/m2 and below 35 mcd/lx/m2 under wet and rainy conditions. A high contrast ratio between marking and pavement, such as 3:1 or 4:1, shows increased reliability during daytime [31]. The width of the road markings should be at least 12 cm for proper detection. Furthermore, it is important to have continuity of road markings and to remove all traces of old markings from the road surface after renewal.

To achieve those conditions and ensure that road markings and road signs are correctly interpreted by both people and ADAS systems, regular maintenance is necessary. Except for more studies that would include testing during night-time, day-time, heavy rain conditions and with a wider variety of speeds and complex road geometries, future research should be focused on sensor fusion development and its impact on road sign and road markings detection. Those research results would help road authorities develop new standards and policies for the maintenance and design of future road infrastructure.

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