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Speed monitoring and controlling systems for road vehicle safety: a systematic review

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Abstract

Over-speeding continues to be one of the major causes of road fatality and accordingly, several interventions have been designed to combat it. In more recent times, several studies have proposed intelligent methods for detecting, monitoring, and controlling over-speeding effectively. This study investigated advancements, challenges, and future research direction of the use of intelligent speed monitoring and control systems. Using a systematic review approach, 47 studies were identified and reviewed. The review covered studies published from 2015 to 2019. The findings from the review indicated that road vehicle speed monitoring and control systems have witnessed commendable advancements over the past years. Four main types of speed measurement technologies dominate speed monitoring and control systems. Out of the four, sensor-based technologies are the most used, yet they are characterized by low-speed measurement accuracy. Also, studies in the domain use diverging evaluation methods and this makes it a challenge to compare system performance across the various studies. Also, there seems to be a lack of interest in the usage of artificial intelligence and machine learning techniques for speed measurement. The study proposes increased attention to the use of artificial intelligence and machine learning techniques to promote effective speed monitoring and control systems.

Keywords – intelligent speed monitoring, over-speeding, vehicular traffic controls, systematic reviews

1. Introduction

Transportation on road is a major means of human movement because it is relatively cheaper and easier to use. Yet, it is associated with higher incidents of crashes, large agriculture vehicles use and crash incidents on public roads [1] when compared to other means of transport. Currently, road crashes are one of the major concerns of many countries: it affects lives, properties and the environment [2]. Present studies have demonstrated that factors that lead to these crashes include drunk driving, machine failure, and over-speeding [3]. Some studies have argued that most road crashes relate to speed issues [4]. Over-speeding leads to loss of vehicle control and gives drivers inadequate time to react when there is an unforeseen obstacle in the driver's path [3]. More importantly, collision impact at high speeds is deadly: hence increases the seriousness of the crash. It can therefore be concluded that there is a relationship between over-speeding and road crashes [5]. Accordingly, several studies have attempted to address issues on the over-speeding behavior of drivers [1, 6, 7].

Recently, advancements in parallel computing and algorithms have made it possible for machine learning (ML) and artificial intelligence (AI) techniques to be applied for addressing road safety issues. Applications and systems such as cruise control (adaptive and cooperative) [8], emergency braking systems and active suspensions [9], speed control systems [5, 7] and advanced driving assistance systems [10] have all been proposed. These systems have contributed to the safety of all road users, yet the mechanisms adopted by these systems to control over-speeding must be improved. This is because issues regarding over-speeding continue to gain attention considering that many road crashes are speed-related [4].

Accordingly, research and practice on the use of intelligent methods for monitoring and controlling vehicle driving speed have advanced. However, studies on the current state of the art, or studies that seek to present summaries and reviews on research relating to contemporary methods for controlling over-speeding are lacking. Nonetheless, such information is pertinent considering that interventions that seek to address over-speeding behavior need to focus on two main issues: technology and human behavior change techniques. Now, considering the vast number of studies in speed measurement techniques and human behavior change approaches calls for the need to investigate how researchers in the community seek to address road vehicle over-speeding in modern times.

This study, therefore, systematically reviews and summarizes studies that have employed artificial intelligence to combat on-road vehicle over-speeding. In the next section, a discussion on related work is presented. This is followed by the method adopted for performing the review. The findings, implications, and limitations of the study are presented before conclusions are drawn.

2. Related work

Generally, speed monitoring and controlling systems for enforcing traffic laws can be categorized into active and passive systems [10]. Passive speed monitoring and control systems are mostly embedded in road infrastructure or smart vehicles. In some cases, the owner of older vehicle models installs retrofits to enable them to monitor and control their speeding behavior. Passive speed monitoring or control systems do not enforce laws directly, however, they seek to advise or guide road users to follow traffic regulations. Active systems, on the other hand, seek to enforce traffic regulations covertly. They may include the use of police officers stationed at specific locations to ensure that road users abide by traffic regulations. Regarding over-speeding behavior, conventional speed cameras are one of the most active ways of controlling speeding. Whilst some researchers have demonstrated that speed cameras are effective for controlling over-speeding behavior [11], some have argued that they may not be effective in areas or jurisdictions where there are poor addressing systems [7]. As mentioned earlier, the use of AI methods for monitoring and controlling speed on roads is gaining popularity. Speed assistance technologies fulfill the purpose of informing drivers of the speed limit in specific regions. They have alert systems that give drivers the choice to react to speed limit violations. They offer awareness and comfort when compared to traditional systems [5] and serve as an efficient approach that augments existing road safety campaigns. Yet, studies that discuss contributions and advancements made by Speed Assistance Technologies (SAT) particularly those that use AI methods are not adequate.

To eliminate ambiguity in this study, intelligent speed monitoring and control systems are considered to be systems that are designed with the intention to control a driver's speeding behavior. Particularly, they employ some form of technology that can sense or detect a road vehicle, measure its speed and communicate the speed to the driver to make the driver drive within limits and other regulations. They do not include the use of Radar (Radio Detection and Ranging) and Speedometer

Clocks. Although, some studies have attempted to provide relevant summaries on generic speed management systems, to our knowledge none have focused on those that use some form of intelligence as defined in this study. For instance, Sadeghi-Bazargani and Saadati [12] reviewed generic speed management strategies and reported that most of the existing studies on speed management were performed in Europe and they mostly use speed cameras and engineering schemes for managing over-speeding. Others [13] reviewed research on 'on-road vehicle detection using optical sensors' and outlined the challenges that impede the use of optical sensors for vehicle and speed detection. Some have also discussed the techniques and methods of urban speed monitoring in intelligent transport systems [14] road markings and their impact on driver behavior [15], large agriculture vehicles and crash incidents [16] as well as motion planning techniques for automated vehicles [17]. While these studies are relevant to road safety and speed management, in particular, they fail to discuss the pertinent issues on intelligent monitoring or controlling over-speeding. Specifically, questions relating to how and where these monitoring systems are installed (i.e., within the vehicle or on the roads), the technique used for measuring the speed, the intended purpose of the technology (to alert, persuade or coerce) among others remains unanswered. Yet, these questions are crucial for directing successful future investigations in the vehicular speed management system.

3. Review approach

The objective of this review is to systematically identify and review research in speed monitoring and control mechanism on roads that adopt some form of artificial intelligence. Thus, the study conformed to the systematic review approach as proposed by Kitchenham and Charters [18]. This approach has been successfully used for investigating trends in Software Engineering [19], Machine Learning for Recommender Systems [20], AI and Cybersecurity [21] and the classification of heart sound [22]. Even though systematic reviews do not provide a holistic review on all issues in a specific research area, it provides a means for summarizing the most relevant literature in a research area. It is auditable and also characterized by minimal error. According to Kitchenham and Charters [18], the development and use of review protocols guide systematic review studies, and also provide near to accurate information with fewer biases. Consequently, a review protocol was developed to provide a framework for directing and crafting the review questions, search strategy formulation, article selection, data extraction, and analysis. Table 1 is a list of review questions and their related objectives that the study seeks to address.

Although there are several academic databases available, a selection of the most relevant databases was used. A preliminary search revealed that IEEE Xplore (IEEE); ScienceDirect (SciDir); ACM Digital Library (ACM DL) and Scopus provide a comprehensive list of academic works in the domain. In particular, Scopus provides accredited journals and conference proceedings. Although Google Scholar produced a larger number of articles during the initial search stages, it was omitted because it was a challenge to identify studies that were published in predatory journals and thus not suitable for this study from Google Scholar. This is because the quality of articles published in predatory journals cannot be ascertained since most of them are not peer-reviewed. Also, it was observed that most of the publications listed in Google Scholar that were of reputable quality were also available in the Scopus database.

Five (5) key phrases were considered appropriate for the search after the preliminary search (See table 2). This is because they provided the optimal results (i.e., relevant studies from the various databases).

Tab. 1 - Review questions and their motivations

	Research Question	Objective
RQ1	What is the publication trend in intelligent over-speeding monitoring and control systems?	To identify the distribution of studies between 2015 and 2019. Which publication is receiving attention, what is the geographical distribution of research and what is possibly motivating these trends?
RQ2	What intelligent speed measurement technologies are used in these systems?	To identify the various intelligent approaches used in monitoring and controlling over-speeding on roads. What technologies are dominating and why? What are the weaknesses of the various technologies and how can they be addressed?
RQ3	Are these systems installed in the vehicles or on the roads?	To identify the mode of installation of the various systems and their possible impact on success.
RQ4	What behavior change mechanisms do they adopt?	To identify the dominant intentions for implementing speed control mechanisms
RQ5	What improvements have been made in intelligent speed monitoring and control technologies?	To identify improvements in intelligent techniques used or monitoring and controlling speed.
RQ6	What are the current limitations, challenges, and future directions in intelligent speed monitoring systems?	To identify the limitations of current methods in the domain and provide discussions on future research to guide both novice and seasoned researchers in the domain.

Tab. 2 - Number of studies identified from each database

Database	Keywords	Time (17/7/2020)	Studies returned
IEEE	Intelligent vehicle speed control mechanism	3:13 pm	76
	Intelligent vehicle speed measurement	3:21pm	308
	Speed limit violation	3:25pm	43
	Intelligent vehicle over-speeding control	3:28 pm	10
	Driver warning system	3:33 pm	573
SciDir	Intelligent vehicle speed control mechanism	3:40 pm	4
	Intelligent vehicle speed measurement	4:10 pm	11
	Speed limit violation	4:34 pm	42
	Intelligent vehicle over-speeding control	5:01 pm	1
	Driver warning system	5:05pm	194
ACM DL	Intelligent vehicle speed control mechanism	5:23 pm	2234
	Intelligent vehicle speed measurement	5:45 pm	1586
	Speed limit violation	5:56 pm	164
	Intelligent vehicle over-speeding control	6:10 pm	2191
	Driver warning system	6:18 pm	2671
Scopus	Intelligent vehicle speed control mechanism	3:13 pm	68
	Intelligent vehicle speed measurement	3:21 pm	293
	Speed limit violation	3:25 pm	145
	Intelligent vehicle over-speeding control	3:28 pm	8
	Driver warning system	3:33 pm	1490
Total			12,122

These key phrases are (1) ‘intelligent vehicle speed control mechanisms’; (2) ‘intelligent vehicle speed measurement’; (3) ‘speed limit violation’; (4) ‘intelligent vehicle over-speeding control’; (5) ‘driver warning system’. It is worth mentioning that search phrases were crafted to ensure that generic speed detection and prediction studies that do not seek to monitor or control over-speeding of road vehicles are not selected. This is because the study intends to investigate speed monitoring and control technologies that employ artificial intelligence to combat over-speeding. The five (5) phrases were used to search for studies in each of the five databases from 2015 to 2019. This resulted in twelve thousand, one hundred and twelve (12,112) identified studies (see table 2).

Based on the protocol, the studies from the search results were further filtered using the inclusion and exclusion criteria. First, the titles and abstracts of the 12,122 studies were screened. Studies whose titles or abstracts did not suggest the use of artificial intelligence for controlling road vehicle speed were excluded. Secondly, book chapters, edited books, workshop proceedings, columns in magazines, and book sections were excluded. Thus, only studies from peer-reviewed journals and conferences were used. Next, duplicate studies were removed from the list of studies before review studies were excluded. This brought the number of studies to sixty-nine (69). However, forty-seven (47) were used because 22 of them did not provide the relevant information needed for this investigation. Although snowballing was used to identify relevant studies that meet the criteria but are not in any of the five databases, no study was identified. Figure 1 shows the stages of the study selection process and the corresponding number of studies selected at each stage.

A spreadsheet was used to tabulate data from the various selected articles. Two (2) researchers from the research team extracted the relevant data from the various articles by reading each article and answering each of the review questions listed in Table 1. The final extracted data was validated by the other two members. The entire team (4 members) met and addressed conflicts and disparities in the information gathered.

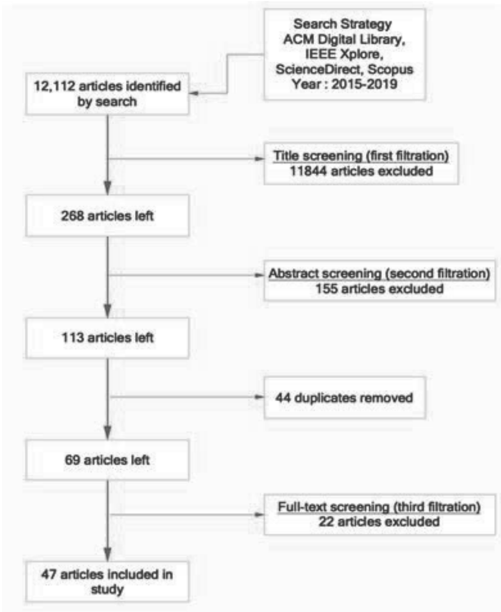

Fig. 1 - Stages in study selection

4. Results and discussion

4.1. Publication trends and distribution of studies (RQ1)

The findings revealed that more than half of the studies were published between 2018 and 2019. Out of the forty-seven (47) studies, eleven (11) were published in 2018 and eighteen (18) in 2019. Generally, there has been a steady growth in the number of studies within the past five years. Also, the majority of the studies were published in conference proceedings when compared to journals. Thirty-three (33) out of forty-seven (47) were conference proceedings and most of the studies originated from Asia (i.e., 70% of the studies have either the first or corresponding author's address in Asia). Studies originating from Europe accounted for twelve percent (12%) of the total, whereas those from North and South America formed ten percent (10%). Six percent (6%) of the studies were from Africa. Figures 2 and 3 are a diagrammatic representation of distribution patterns over the years and the geographical distribution respectively.

4.2. Types of speed measurement technologies (RQ2)

A key ingredient in speed monitoring and control systems is their ability to determine the speed of the vehicle being monitored or controlled. Due to the broad spectrum of technologies available, different methods are used for this purpose. These methods or technologies mostly adopt or depend on other technologies: thus, it is a challenge to categorize them into specific classes or groups. Nonetheless, the study observed that the various technologies can be grouped into four broad types, namely: camera-based, sensor-based, phone-based, and wi-fi-based systems. This classification is based on the technology used to measure the speed of the vehicle, but not the technology used in communicating the speed.

4.2.1. Sensor-based speed measurement technologies

Sensor-based speed measurement technologies employ active sensors in their operation. Unlike passive sensors, active sensors possess real-time detection capabilities and are effective in adverse weather conditions such as rain and fog. In general, sensors can be further divided into subgroups based on their location, i.e., intrusiveness and non-intrusiveness.

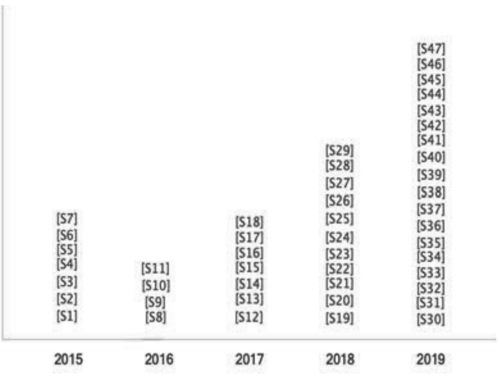

Fig. 2 - Distribution of articles per year

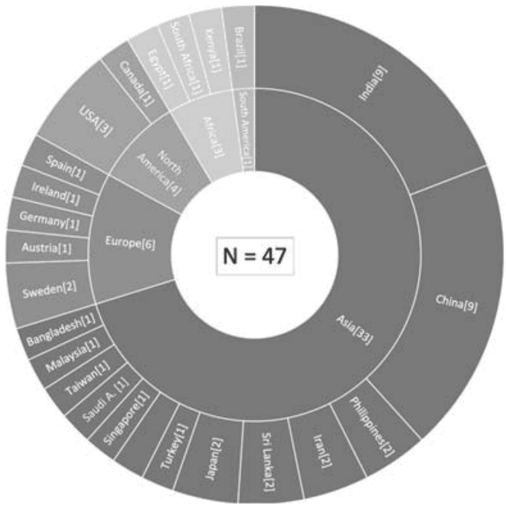

Fig. 3 - Distribution of continent and countries

While intrusive sensors are deployed on pavement surfaces and have high accuracy without being affected by weather conditions, non-intrusive sensors can be deployed at different locations on the roads, but their accuracy is dependent on weather conditions. They are characterized by slow scanning speeds, susceptible to interference from other signals, and are expensive to install and maintain.

The study revealed that sensor-based speed measurement technologies were the most used tools in road vehicle speed monitoring and control systems. It accounted for more than half (i.e., 51%) of the total number of studies reviewed. These technologies employ active sensors in estimating vehicle speed. Active sensors assess the effects that passing vehicles have on transmitted signals from sensing devices to estimate speed. In some cases, these systems transmit data wirelessly using wireless sensor networks. They measure relative speed and distance with less complex computations. It was observed that sensing devices including Infrared sensors, Ultrasonic sensors, Shimmer sensors, and Hall Effect sensors dominate vehicle speed measurement technologies. Sensor-based technologies have a high percentage of errors in measurement and low accuracy (discussed later in this section). Its usage has grown over the past five years as four systems were recorded to use it in 2015, and 10 out of the 18 studies in 2019 used a sensor-based speed measurement technology.

4.2.2. Camera-based speed measurement technologies

Camera-based speed measurement technologies employ cameras as the core technology for measuring the speed of a vehicle. They accounted for thirty-eight percent (38%) of the studies reviewed. Unlike traditional speed camera systems that use detectors embedded into the road surface or radar technology to detect the speed of passing vehicles, Camera-based speed monitoring and control systems use non-intrusive passive means to determine the speed of vehicles. They operate using computer vision techniques that capture and analyze still images or video streams of moving vehicles. Since they use non-invasive methods of acquiring data (i.e., through the use of images), they are relatively cheaper to implement. Due to advancements in technology, many cameras have been integrated with optical sensors which enhance their effectiveness even in low-light conditions. They are easily deployable and can be installed regardless of modifications to road infrastructure. Camera-based speed monitoring and control systems are characterized by less maintenance cost when compared to sensor-based technologies but are easily seen by road users. Consequently, some drivers adjust their speed to conform to speed limits when they encounter them. Hence, they are only effective within a short range from the installation point.

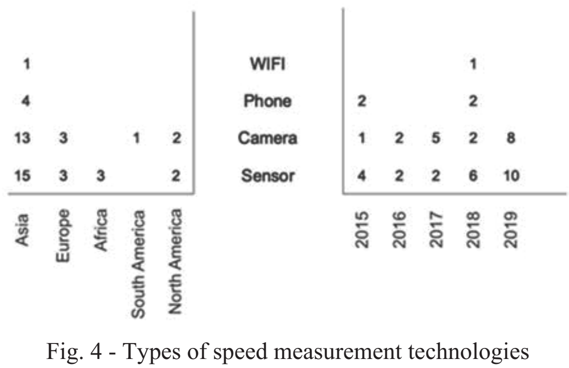

Fig. 4 - Types of speed measurement technologies

The number of studies that adopted Camera-based speed monitoring and control systems (see table 3 and figure 4) demonstrate that the technology is gaining attention in speed monitoring and control research in recent times. New camera-based speed measurement technologies are capable of providing precise speed with higher accuracies. Distance estimation errors have been drastically reduced. It was observed that camera-based speed measurement technologies designed for monitoring and controlling speed are capable of detecting speed with accuracies between 81% to 90%. The level of accuracy was observed to be dependent on the resolution of, and the number of cameras used for measuring the speed. This finding confirms existing claims [23].

4.2.3. Phone-based speed measurement technologies

Another form of speed measurement technology observed from the selected studies was phone-based systems. Four studies (8%) adopted mobile telephony technology to measure speed. Phone-based speed measurement technologies employ a variety of tools embedded in mobile devices to estimate the speed of vehicles. They may either operate online or offline on the device, and they mostly combine Global Positioning Systems (GPS), microphones, gyroscope, accelerometer, camera, and other sensors depending on the level of sophistication. They may also use cell residence times of smartphones to estimate vehicle speed. They have limitless coverage when compared to camera and sensor-based technologies. Thus, they cover the entire stretch of the journey since the device is placed in the vehicle; compared with sensor and camera-based measuring technologies that are mostly stationary, and thus measures the speed of the approaching vehicle at a specific point or range.

The main challenge of using mobile phones for estimating speed is the complexity of operations it performs. As compared to camera and sensor-based technologies that are mostly designed to collect specific information, phones are not primarily designed to measure speed. Thus, speed monitoring applications share device resources with other applications, and this affects the performance of the measuring instrument. Especially in cases where there is an incoming call. Again, the multi-purpose nature and heavy use of personal phones result in reduced battery time. However, the versatile capabilities of phones enable the collection of other relevant related data that may not be easily acquired from camera and sensor-based systems. For instance, phone-based speed monitoring systems are capable of collecting information on GPS location, sound, images, and even activities around the immediate environment of the vehicle in addition to its speed throughout the journal time. The relatively low number of studies that adopted this technology is intriguing considering the ubiquitous nature of mobile devices. Particularly, all four studies were performed between 2015 and 2018: two studies each year. This demonstrates a lack of interest in the use of mobile devices for measuring and controlling speed, although it is expected that these systems will be more effective in speed controls.

4.2.4. Wi-fi based speed measurement technologies

This technology was used in only one study. Wi-fi-based speed measurement technologies use device-free systems and models to estimate the speed of vehicles by analyzing their effect on surrounding Wi-fi signals. They are capable of analyzing the influence of vehicles on surrounding wireless signals including those emitted from roadside wireless infrastructures. A pair of wireless nodes are installed on each side of the road (one node sends signals continuously and another receives signals sent by the first node to estimate speed). Vehicles are automatically detected once they move between the line of sight of the two nodes. This enables the system to estimate the speed of the vehicle. Though such systems work as intended, there may be surrounding Wi-fi or Bluetooth signals that could interfere with it, and this affects system performance. The findings revealed that Wi-fi based systems were the least adopted method. From table 3, it can be observed that only one study used it and this study was performed in 2018.

4.3. Locations of speed monitoring installations (RQ3)

According to the study, there are two main methods for installing speed monitoring and control systems. These are installations inside the vehicle (in-vehicle) and installations on a physical location outside the vehicle (on-road). In-vehicle installations require that the speed monitoring device is placed inside the vehicle. Mostly, these systems measure the speed of the vehicle by calculating the displacement of the installation. The speed monitoring device may either be visible and removable (e.g., portable mobile devices including phones) or may be hidden from the driver (e.g., a speed sensor installed in the dashboard). On-road installations measure vehicle speed by calculating the displacement of the vehicle with respect to time relative to the location of the installation. Although some speed monitoring and control installations combine both in-vehicle and on-road installation methods to monitor speed, those that use on-road only are the majority. The study revealed that 59% of the total number of studies reviewed installed their systems on the road. Systems with in-vehicle installations were 32% and the remainder combined in-vehicle and on-road installations.

Research on in-vehicle installation has not increased over the years when compared to on-road installations. From Figure 5, out of the total of seven (7) studies in 2015, there were five (5) in-vehicle installations, one (1) on-road installations, and one (1) installation that combined both in-vehicle and on-road infrastructure. In 2016, one (1) study was related to in-vehicle installation, two (2) related to on-road installation and one (1) was associated with an installation that combined in-vehicle and on-road infrastructure. Also, in 2017, none of the studies examined infrastructure that combines in-vehicle and on-road installation. One (1) study was related to in-vehicle installation and another six (6) investigated on-road infrastructure. Similarly, no study was conducted on installations that combined in-vehicle and on-road infrastructure. Moreover, eight (8) studies were performed on on-road installations and three (3) studies were on in-vehicle installations. However, in 2019, eleven (11) out of the eighteen (18) studies adopted on-road installations. Perhaps the increase in on-road installations corroborates with the argument that drivers do not prefer that systems are installed in their vehicles to track their speeding behavior [24]. Again, the findings justify the relatively low use of phone-based speed monitoring systems, since most phone-based monitoring systems are placed inside the vehicle.

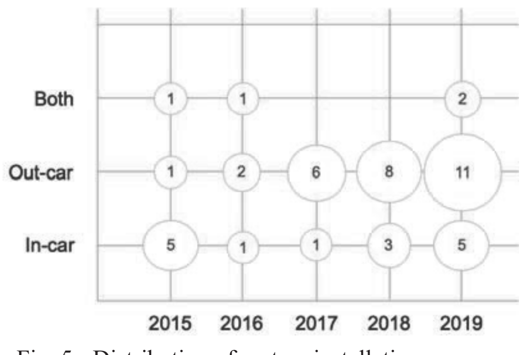

Fig. 5 - Distribution of system installation vs years

On-road installations are relatively easier to implement because they do not need the consent of drivers and other road users. Besides, they can be less susceptible to manipulation by drivers when compared to in-vehicle installations. In some cases, they are overt (e.g., speed cameras) and their presence serves as a deterrent to offending drivers. They are mostly cheaper to implement as only a few devices are installed on roads to collect data. However, for in-vehicle systems, a device is installed in each vehicle which increases the cost of implementation exponentially. It may be argued that visible on-road speeding monitoring systems are relatively ineffective for monitoring the over-speeding behavior of an entire journey. Rather they are effective at locations where they are installed. Although on-road installations are widely used, studies must investigate how to encourage in-vehicle installations. This is because they are more effective since they are placed in the vehicle through the entire stretch of a journey compared to static on-road installations that measure speed within a specific stretch of the road.

4.4. Intentions of speed monitoring and control systems (RQ4)

Although existing speed monitoring and controlling systems seek to ultimately alter driver's speeding behavior (i.e., make them reduce their speed or drive within speed limits), designers of these systems employ different design intents to achieve this goal. It was observed that existing speed monitoring systems are installed to alert and warn, persuade or coerce drivers to reduce their speed. Some systems are also installed to report speeding drivers to the appropriate authority. In Figure 6, the studies are categorized based on their design intents.

Alert and warning systems mostly adopt sensor-based monitoring technology to collect the current speed of the vehicle and alert or warn the driver of their current speeding behavior. In some cases, they transmit data wirelessly to a central computer (server) for further investigation. Such systems are investigative and do not seek to penalize drivers for flouting speed limit laws. Sometimes, the data collected are used to design and model algorithms to better understand driver behavior. Out of a total of forty-seven (47) studies, thirty-seven (37) of them were designed to either alert or warn drivers of speeding behavior. Although all vehicles are equipped with speedometers to inform drivers of their speeds, it is expected that an additional form of interaction that seeks to communicate the current speed as an alert system induces a sense of behavior change. Eleven (11) out of these studies had additional capabilities of report offending drivers to the appropriate authorities and such systems are mostly on-road installations. Three (3) out of the forty-seven (47) articles were designed to fulfill two or more intentions. This is illustrated in Figure 6. Again, systems that report offending drivers mostly use sensor-based measurement technologies. This is because eleven (11) out of the twenty-four (24) studies that used sensor-based technology for measuring speed were designed to report over-speeding offenses. Camera-based technologies were also observed to be effective for reporting offending drivers: they provide evidence to support offenses. Specifically, systems that collect traffic violation detection and reporting systems used camera and sensor-based technologies whereas those that sought to warn or inform drivers about their speeding behavior only mainly used phone or sensor-based technologies.

Systems that sought to coerce or persuade drivers to reduce or conform to speed limits were the least since only one study was identified to focus on persuasion and another on coercion. However, the study that focused on coercion was also intended for reporting, alerting, and warning speeding drivers, making it one of the three (3) articles spoken about earlier. Figure 6 provides the distribution of the various system intents per year and the speed measurement technology that was used.

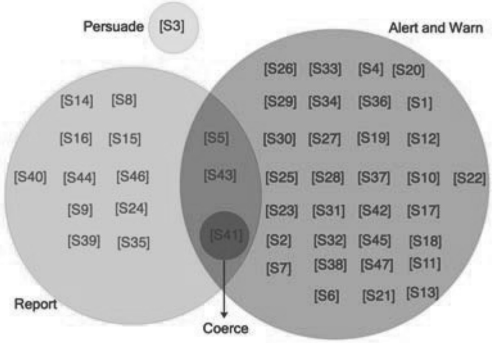

Fig. 6 - Venn diagram illustrating overlapping system interests

4.5. Improvements in speed measurement techniques (RQ5)

The findings from the study revealed that several improvements have been made in road vehicle speed monitoring and control systems over the past years. Especially measurement accuracy has improved. The lowest accuracy was observed in sensor-based speed monitoring systems with an accuracy of 76% and the highest accuracy reported was 99.5%. The average of reported accuracies was 93.2% with a lower quartile of 88.5%, median of 95.6%, and upper quartile of 97.9%. This demonstrates that the accuracies of speed measurement technologies for speed monitoring systems have improved over the years. In particular, camera-based technologies reported an average of 93.5%, whilst phone-based reported an average of 92.6% and sensor-based had an average of 91.7%. Thus, camera-based speed monitoring technologies outperform other technologies.

Sensor-based speed monitoring technologies on the other hand perform relatively poorly when compared to the other technologies. More importantly, this study revealed that out of the twenty-two (22) studies that failed to report how their systems were evaluated (system evaluation was not done nor the accuracy of the speed measurement technology adopted reported), seventeen (17) were studies that used sensor-based technologies.

Different camera setups were observed in the review with some camera-based systems using a single monocular camera [S11, S18] and others using a stereo-vision setup with two (2) cameras [S31, S10]. These systems also used image processing techniques to detect and track vehicles across multiple video frames. The use of background subtraction which extracts vehicles across multiple frames to calculate their speed [S36, S45] was also identified. Some studies also used feature extraction and point matching methods to select features on vehicles and track them [S44, S45]. Whereas others used feature detection methods with vehicle license plates as the chosen reference feature [S31, S12, S34, S10]. Multiple reference lines were also used for identifying vehicles and the number of frames the vehicle took to cross over the reference line to estimate the speed [S13].

4.6. Challenges and limitations of measurement techniques (RQ6)

4.6.1. Speed measurement accuracy

Although the study revealed that accuracy in speed measurement technologies has been improved over the years, there is a need for more improvement. The current recorded average accuracy of 93.2% is not adequate. This challenge is highly associated with sensor-based techniques (that recorded an average of 91.7%). There is, therefore, the need for investigations to pay attention to improving the accuracy of sensor-based speed measurement technologies considering that it is the most used form of speed measurement technologies in speed monitoring and controls. Perhaps, the use of extensive machine learning techniques may help alleviate this challenge.

Moreover, the accuracy of sensor-based monitoring and control systems is hindered by the topographic conditions of the roads. The nature of roads (e.g., road gradient) affects vehicle speed patterns. The acceleration requirements for vehicles that are descending hills differ from those that are climbing. Therefore, topography issues affect the description of the speeding patterns of vehicles. Sensor-based speed monitoring and control systems must consider such contexts in their estimations and descriptions of vehicle speeding patterns. Interferences from other sources such as vibrations of heavy-goods vehicles, broadcast signals from radio and network towers as well as adverse weather conditions such as rains may also affect sensors. To eliminate these challenges, a multimodal approach to speed detection can be employed. Indeed, none of the studies reviewed adopted such an approach. Nonetheless, when speed monitoring and control systems adopt multiple speed detection strategies, they may produce more accurate speed measurements. For instance, camera-base systems may augment some of the defects of sensor-base systems.

4.6.2. Standardized evaluation

There is a lack of a universally accepted standard for speed error estimation and accuracy. It was observed from the primary studies used in this investigation that methods used for evaluating the accuracy of the speed detecting devices in the various studies are diverging. Methods ranging from a field test in a real-world environment, through using video recordings from a real-world to simulations were used. Some studies also evaluated their systems based on comparisons with either a selected reference speed or a correct speed stated in a dataset. Thus, it is a challenge to ascertain the true accuracy of the measures recorded. This emphasizes the need for adopting a universal method of evaluation in such studies.

Several studies (23 out of 47) employed simulation for evaluating speed monitoring and control systems. Undeniably, these approaches present some coordination in terms of how the system designed may operate in real-life scenarios. However, situations in real-life instances may not be accurately presented in simulated environments. For example, some situations which may influence speeding behavior such as reactions to emergencies, running late to an event, among others may be challenging to simulate.

4.6.3. Coverage range and image detection in camera-based systems

Challenges relating to the coverage range associated with camera-based systems have not received adequate attention. Although camera-based systems have improved measurement accuracy, the ability of cameras to cover a larger stretch of the road remains unsolved. Specifically, most camera-based speed monitoring and control systems are installed at regular intervals to cover a particular stretch of the road. Therefore, the speed of vehicles can only be captured when a vehicle is within the range covered by a camera. Drivers who are familiar with these camera installation intervals may decide to adhere to the speed limit regulations only when they approach the range covered by a camera. This challenge is pressing in camera-based systems, yet it appears less attention is given to it. Although it may be argued that this challenge is generic to all systems that rely on cameras, it was observed that existing studies in the domain fail to adopt some of the most sophisticated camera technologies available.

Furthermore, although technological advancements have enhanced the effectiveness of cameras to capture images even at night, camera lenses are still prone to damages from certain weather conditions such as snow, wind, and heat. Nonetheless, less attention is given to camera-based speeding monitoring and controlling research regarding vision improvement. Considering that the cameras used in these systems are expected to capture fast-moving objects, there is the need for improved camera shutter speed without compromising the amount of light the camera sensor receives. Also, to estimate the speed of moving vehicles using cameras, the vehicles must first be detected with the help of feature detection algorithms. However, vehicle detection is a challenge because vehicles differ in size, shape, and color. Additionally, the detection and tracking of vehicles could be adversely affected if low-quality images are captured. Feature detection algorithms rely on high-quality images to properly identify the features of a vehicle. The quality of images captured could be adversely affected by lighting changes, messy backgrounds, fog, and weather conditions. The majority of the articles studied stated that their systems had inconsistent processing times and the accuracy of the vehicle detection was low. This also confirms the need for further investigations for improving image processing techniques.

4.6.4. Perception of camera as surveillance systems/privacy issues

As indicated earlier, speed monitoring and control systems may be installed in-vehicle or on-road. From the review, vehicle speed monitoring devices may be subject to tampering. This is because many in-vehicle speed-monitoring devices are accessible to drivers. For instance, phone-based systems are in-vehicle systems that can be easily accessed by drivers. However, in a driver's quest to evade monitoring, they may tamper with the device. In-vehicle systems also pose many privacy and security issues which discourage their adoption. Since the displacement of the device is used to calculate vehicle speed, users may perceive them to be intrusive and perhaps invasive of their privacy. This may contribute to why phone-based systems have gained less attention. For the proliferation of in-vehicle systems, researchers must explore what influences users' perceptions of in-vehicle speed monitoring and control systems. This will guide designers to develop monitoring systems that are perceived to be less intrusive and invasive.

4.6.5. Lack of adoption of ML techniques

It was observed that although the studies reviewed demonstrated the use of some form of artificial intelligent techniques, few used machine learning methods. Yet, advancement in machine learning algorithms and techniques suggests that it can be used to successfully predict or determine vehicle speed with higher accuracy. For instance, Deep Learning and Hidden Markov Models techniques have been demonstrated to be promising in predicting vehicle speed [25, 26].

The quest to enhance speed measurement accuracy resonated among all the studies reviewed. This emphasized the need for newer and more efficient algorithms that will outperform existing ones. However, critical observation of the studies demonstrates that researchers in the domain have failed to be adventurous. For example, studies that explore other avenues including the use of acoustic signals and light intensity for detecting and predicting speed for monitoring and controlling purposes are lacking.

5. Discussion

5.1. Implications for research and practice

The use of AI to reduce or control over-speeding on roads is relatively advancing. This fact is backed by the literature reviewed in this study that revealed that studies in the domain have increased exponentially with over sixty percent (61.7%) of the research work reviewed being published between 2018 and 2019. This corresponds to recent advancements in AI and parallel processing. Indeed, compared with traditional speed management methods, AI methods have many advantages in effectively reducing over-speeding on roads and decreasing the number of injuries and casualties due to over-speeding [27]. From the abovementioned review, the essence of finding related literature that employed AI methods was to discern the popularity and effectiveness of these methods in curbing the flouting of speed limit laws. Reports from the review disclosed that although strides were being taken in this new and exciting research area, machine learning methods are less used.

Also, all the systems reviewed claimed directly or indirectly that they are designed to control on-road over-speeding, yet the majority were designed to collect speeding data only. As indicated earlier, over fifty percent were designed with the intent of collecting traffic and speed data whilst paying less attention to alerting drivers. This is particularly worrying because collecting speed data alone cannot sufficiently intervene in speeding behavior. Other methods that may be effective for speed controls were used sparingly: considering that 4.25% of the methods were coercive and persuasive. In particular, the need to use persuasive technologies is currently lacking in the domain. This needs to be emphasized. Persuasive technology is the use of information technology tools and gadgets to deliberately alter user behavior [28, 29]. It has been demonstrated to be effective in addressing behavior change issues in health and wellbeing [30], environment preservations [31], energy conservation [32] and knowledge sharing [33]. Yet, it has been less adopted in over-speeding control.

The study also revealed that Asian countries (70.2%) are leading research advancement in speed management and control methods when compared to other countries. It was intriguing to observe that American (10.6%) and African (6.4%) countries are paying less attention in the domain. This finding contradicts studies performed by Sadeghi-Bazargani and Saadati [12]. Perhaps, it can be argued that speed control research has been intensified in Asia in recent times considering that Sadeghi-Bazargani and Saadati study [12] was conducted in 2015.

5.2. Limitations of study

Although the review process followed systematic review processes as suggested by Kitchenham [34, 35] some limitations were observed. The study used five databases for the entire investigation process, and it is acknowledged that even though these databases are comprehensive and thus contain the majority of related studies, they are unexhaustive. This is to say that there is the possibility that some articles were omitted. As argued earlier, scholarly databases such as google scholar produced more articles, yet it was a challenge to filter peer-reviewed quality studies. It was also observed that search queries from databases such as IEEE Xplore and ACM DL are not consistent in all cases. This has been confirmed by Landman et al [36]. To alleviate this, a snowball approach was adopted to further identify related studies, yet no study was identified using the snowball.

6. Conclusion

This study presented a 5-year review of speed monitoring and controlling systems from 2015 to 2019. Kitchenham and Charters' [18] guidelines for performing systematic reviews were employed to develop the review question, search strategy, and procedures for article selection, data extraction, and analysis. The findings from the study identified 47 articles and demonstrated that research in the domain is progressing steadily with an exponential increase from 2018 to 2019. Four main categories of speed measurement technologies were observed and out of these, sensor-based speed measurement technology was found to be popular yet, it recorded the least measurement accuracy. Camera-based speed measurement technologies had the highest measurement accuracy. Although the majority of the systems reviewed claimed directly or indirectly that they are designed to control on-road over-speeding, they were mainly used to collect speeding data only. Based on the findings it is recommended that more attention must be given to speed monitoring and control systems with persuasive intent since persuasive technologies have been demonstrated to be effective in related domains. Also, there is a need for researchers in the domain to consider machine learning techniques since they are indications that they will increase measurement accuracy.

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Appendix

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