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Review

Identification of Warning Situations in Road Using Cloud Computing Technologies and Sensors Available in Mobile Devices: A Systematic Review

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Abstract: The use of mobile devices connected continuously to the cloud is increasing, and the development of a cloud-based solution may power the function of these devices in mobility. Several types of sensors available in the mobile devices may allow the acquisition of different kinds of data, including inertial sensors, magnetic sensors, location sensors, acoustic sensors, and imaging sensors. The primary purpose of this study is to review the methods, features, and studies related to the identification of road conditions and warning situations. We performed systematic research to discover relevant studies written in English for the identification of different situations using the sensors available in the mobile devices, published between 2011 and 2019. After that, we analyzed the remaining studies to verify its reproducibility. The major part of the studies does not report the accuracy in the detection of warning situations. As future work, we intend to develop a system based on the Centre of Portugal for the detection of warning situations, road problems, and other issues verified during driving activities. As future work, we intend to develop a system using only a mobile device for the acquisition of sensors data in the centre of Portugal. We verified that the majority of the studies were performed in big lands, but in small areas, the number of accidents and road abnormalities is also high.

Keywords: cloud computing; traffic; sensors; mobile devices; vehicles; systematic review

1. Introduction

During recent years, different approaches have taken into account the use of cloud computing. One of the most important topics is the possibility to store large amounts of data or execute the data processing in the server-side with fewer delays [1,2]. The technologies of cloud computing have been improving, and the speed of the network is increasing in the 5G technologies [3,4].

Cloud services provide a connection to different mobile devices and several functionalities available. Some manufacturers (e.g., Google [5], Huawei [6], and Apple [7]) provided their cloud services to the users store different types of data, including contacts, pictures, videos and data related to health. However, the acquisition and processing in real-time of the data acquired from sensors may increase the functionalities of the mobile devices. However, it requires that the mobile device is always connected to the network, although it can reduce the battery lifetime and the processing capabilities of the mobile devices. On the other hand, it increases the functionalities of the mobile devices [8,9].

Based on the data acquired from the sensors available in the commodity mobile devices, the purpose of this study is to analyze the papers available in the literature related to the use of cloud computing technologies for traffic management.

Road abnormalities are one of the significant problems related to traffic accidents. Traffic accidents are causing a large number of victims. The accurate detection of the different accidents is vital for the fast actuation of the emergency responders [10]. In Iran, a significant amount of traffic accidents by car is verified in male people aged between 20 and 39 years old [11]. According to the authors of [12], road problems are the cause of 3.1% of the accidents in Africa. To solve these problems, in Iran, the authors of [13] developed a system to identify with the smartphone the location of the road problems that can cause traffic accidents. In contrast, in London, the authors of [14] presented a methodology for Portuguese local authorities to use the limited resources available to prevent and detect the traffic accidents in urban areas, and to support the implementation of road safety techniques. Another study performed for Portugal was tested in Madeira Island to identify the traffic accidents in real-time to provide accurate information to the drivers [15].

The traffic accidents can be caused by numerous factors that involve a poor road design or maintenance [16], including drop-offs at the pavement edge, improper banking of curves, failure to install traffic signals, and missing or defective guardrails. In addition, the inadequate lighting, potholes, uneven pavement, poor drainage and standing water on freeways, narrow shoulders or steep shoulder drop-offs, faded centre lines and lack of reflective markers, and insufficient warning signs are other problems related to the roads.

The proposed system uses a real-time collection, organization, and transmission of traffic and road conditions data to provide adequate and accurate information to drivers. to implement in Madeira Island traffic condition problems.

The motivation of this research on the state-of-the-art is the creation of a new system for the mapping of road abnormalities, bumps, breakers, and other warning situations detected during the driving activities. By the end, this system may help to map the drivers' style.

Therefore, the main contribution of this paper is to review the different systems previously implemented related to the recognition of warning situations during driving to create a method for the Centre region of Portugal that identifies the warning situations and prevent the drivers about that. This system will improve security and information during driving.

Before the research, the scope of this review consists of the analysis of the studies published between 2011 and 2019, but we only consider full research articles written in English. Finally, we limited our research exclusively to the studies that combine the use of cloud computing technologies and sensors available on mobile devices.

Our study analyzed 18 of 297 scientific publications searched from three databases (*i.e.*, IEEE Xplore, ACM Digital Library, and ScienceDirect) according to the use of sensors, the methods implemented, the features extracted and the purpose of the study. The studies related to parking assistant and monitoring technologies because they are not related to our ultimate goal. Finally, we verified that all of the research studies made use of the Global Positioning System (GPS) receiver. In addition, the major part of them used the inertial sensors for the detection of warning situations. Unfortunately, the reproducibility of the studies is not possible because the authors did not share their data and source code of the methods publicly.

Based on the studies analysed, Table 1 presents the distribution of the different situations found in the papers analysed, where we found that the significant part of the studies performs the detection of undifferentiated warning situations (56%). Next, the discovery of automobile traffic and accidents at real-time is presented in one of each three studies found in this study. Other problems are detected in minor numbers, including road pavement problems, velocity, location, and road potholes. In contrast, the site of our study, which is placed close to the Serra da Estrela, Covilhã, Portugal, allows the possibility to detect pedestrian crossings, bike paths, places, direction, and road slope.

Table 1. Analysis of the number of studies with different findings.

Events and Situations Found	Number of Studies	Percentage in Total Studies
Undifferentiated situations	10	56%
Automobile traffic	6	33%
Real-time accident	6	33%
Road pavement problems	5	28%
Velocity	4	22%
Location	4	22%
Road potholes	4	22%
Road bumps	3	17%
Acceleration	3	17%
People	3	17%
Road ditches	2	11%
Speed braking	1	6%
Send notifications to the user	1	6%
Road signs	1	6%
Maintenance holes	1	6%
inadequate lighting	1	6%
Pedestrian crossings	1	6%
Bike paths	0	0%
Places	0	0%
Direction	0	0%
Road slope	0	0%

Thus, as future work, we intend to develop a system for the detection of road problems and traffic accidents in the Centre of Portugal, where none of the studies found was performed. Mainly, the studies are presented in the North of Portugal, around the coast of Portugal, and in Madeira Island. In addition, we want to solve one of the major problems of a large part of the studies that consists of the reproducibility of the research, sharing the datasets acquired, and the source code developed publicly. This system will allow preventing accidents caused by road problems and others, providing real-time information to the drivers. This system is not now implemented in the region in the analysis. Still, we want to solve some problems related to the privacy of the data, reliability of the data, and performance of the mobile devices during the data acquisition to increase the usability of the proposed system.

This paragraph finalizes the introduction section. Section 2 presents the methodology of this reviews. Next, we present the results in Section 3. We are finalizing this review with the discussion about the results in Section 4, and the conclusions of this study in Section 5.

2. Methodology

2.1. Research Questions

The primary questions of this review were as follows: (RQ1) How can cloud computing be used for traffic management? (RQ2) Which are the sensors used for traffic management? (RQ3) Which are the warning situations already detected with the sensors available on mobile devices?

2.2. Inclusion Criteria

Studies assessing traffic management using cloud computing were included in this review if they met the following criteria: (1) use of sensors available on mobile devices; (2) use of cloud data for the detection of situations during driving; (3) use of mobile devices; (4) published between 2011 and 2019; (5) were full research articles; and (6) written in English.

2.3. Search Strategy

The team searched for studies meeting the inclusion criteria by title, abstract, and keywords in the following electronic databases: IEEE Xplore, ACM Digital Library, and ScienceDirect. Two reviewers (I.P. and N.G.) independently evaluated every study, and they determined its suitability with the agreement of all parties. The studies were examined to identify the characteristics of cloud computing with sensors available in mobile devices and its suitability for the detection of warning situations in traffic management. The search was performed on the 14th February 2019.

2.4. Extraction of Study Characteristics

The following data were extracted and tabulated (see Tables 2 and 3): year of publication, publication type, population for the application of the algorithm, purpose of the study, sensors used, availability of the raw data and the source code, the environments of the data acquisition, and study outcomes of the system designed.

Table 2. Study analysis.

Study	Year of Publication	Publication Type	Population	Purpose of the Study	Sensors	Raw Data Available	Environment
Soares et al. [17]	2018	Conference paper	Three different drivers, cars and smartphones, with the latter mounted on each vehicle's windshield, using an 'iOttie Easy One Touch 3' holder, with the data acquisition component installed and running	Proposes a cloud-based road anomaly information management service for detecting, identifying and managing road anomaly information.	GPS receiver; Accelerometer	No	City of Braga, Portugal
Demetriou et al. [18]	2018	Conference paper	Undefined number of cars	Proposes a system to provide sensor-rich car's accuracy to legacy cars and assist in the movement of the vehicle in the public highway	GPS receiver; Inertial sensors	No	Real-World
Qiu and Shen [19]	2018	Conference paper	Three vehicles with the mobile phones	Proposes the calculation of the optimal velocity profiles which avoid vehicle collision	GPS receiver	No	Real-World
Celesti et al. [20]	2017	Journal paper	Undefined number of cars	Proposes a system to check the accident data, local and try to predict this type of events	Accelerometer; Microphone; GPS receiver	No	Real-World
Al Mamun et al. [21]	2017	Conference paper	Undefined number of cars	Proposes a system to analyze and detect possible problems related to braking, bumps and automobile traffic	Accelerometer, Compass, GPS receiver; Proximity Sensor	No	Aftab Nagar in Dhaka city
Guo et al. [22]	2017	Conference paper	20 students carrying smartphones in bus and cars	Proposes the investigation of the impact of different in-vehicle locations on the performance for different extreme driving behaviour detection	Accelerometer; Gyroscope; GPS receiver	No	Public transportation in China

Table 2. *Cont.*

Study	Year of Publication	Publication Type	Population	Purpose of the Study	Sensors	Raw Data Available	Environment
Bagheri et al. [23]	2016	Journal paper	Undefined number of cars	Proposes a mobile application to share information about predictions of collisions	Accelerometer; GPS receiver	No	Real-world
Bahadoor and Hosein [24]	2016	Conference paper	group of 6 users for the initial prototype testing	Proposes a mobile application to bridge the gap between negative driving detection and user motivation for safer driving behaviour	Accelerometer; GPS receiver	No	Real-world
Kwak et al. [25]	2016	Journal paper	Undefined number of cars	Proposes a mobile application that sends and receives data related to the road conditions, the time of arrival and eventual incidents	GPS receiver; Cameras	No	Real-World
Laubis et al. [26]	2016	Conference paper	Undefined number of cars	Presents a correlation between the costs of the vehicle, maintenance, consumption and the history of incidents to make an analysis	Accelerometer; GPS receiver	Yes	92.000 km of roads in Sweden in 2014
Savera et al. [27]	2016	Conference paper	Undefined number of cars	Proposes a mobile application to detect possible braking and obstacles	Accelerometer; GPS receiver	No	City of Karachi
Tak et al. [28]	2016	Journal paper	Undefined number of cars	Proposes a system that checks and monitors the risk of collisions based on the distance between two vehicles	GPS receiver; Accelerometer; Gyroscope	No	Real-World

Table 2. *Cont.*

Study	Year of Publication	Publication Type	Population	Purpose of the Study	Sensors	Raw Data Available	Environment
Aung and Naing [29]	2015	Conference paper	One vehicle	Proposes a system to detect traffic condition by analysing the behaviour of vehicle primarily based on GPS mobile phone and history data	GPS receiver	No	Baham Campus to Hlaing Campus and Insein road
Taha and Nasser [30]	2015	Conference paper	Undefined number of cars	Proposed a framework to enable safety-based alerts and road navigation, and recognize road conditions	Accelerometer; GPS receiver	No	Roads in Saudi Arabia
Wu et al. [31]	2014	Conference paper	Undefined number of cars	Proposes the use of vehicles equipped GPS receivers or smartphones to collect real-time traffic information	Accelerometer; WiFi, GSM and GPS receivers	No	Real-World
Basu et al. [32]	2014	Conference paper	One dataset with 2104 independent trajectories, 12 unique locations and 19515 data points, and another dataset with 28340 independent trajectories, 1334 unique locations and 593044 data points	Proposes a method of converting time sequenced trajectory data into the item-based collaborative filtering (CF) domain and have applied a privacy preserving CF predictor to obtain predictions for next location	GPS receiver	No	Italian city of Pisa and Italian city of Milan.

Table 2. *Cont.*

Study	Year of Publication	Publication Type	Population	Purpose of the Study	Sensors	Raw Data Available	Environment
Shi et al. [33]	2012	Conference paper	Undefined number of cars	Proposes an algorithm of large-scale context aggregation designed according to MapReduce Model	GPS receiver; Microphone; Accelerometer	Yes	Real-World
Rodrigues et al. [34]	2011	Conference paper	Undefined number of cars	Proposes a system architecture for a massive multi-sensor urban scanner, which lays out the infrastructure for reliable data gathering and storage of city-scale data sets, making them widely available for processing and analysis	GPS receiver; Accelerometer; Microphone	No	City of Oporto, Portugal

Table 3. Study summaries.

Study	Outcomes
Soares et al. [17]	The authors developed a system mobile that sends roadway information using the cloud communication paradigm and allows the use of massive storage data. The authors implemented the main service by a Python Flask application, deployed as an uWSGI container, and served by a web server. The authors also implemented the map matching technique using the Maps Snap to Roads API used to correct all GPS points captured. A stateless REST Web service, implemented in NodeJS using the Express framework, was used as a road anomaly service. This prototype resulted in the identification of 4611 anomaly records, where 3450 are not anomalies, 158 are maintenance holes, 563 are short bumps, 434 as long bumps and 6 are part of an unspecified class.
Demetriou et al. [18]	The authors developed a mobile system to allow legacy cars to have access to a GPS service as accurate as modern cars. This system allows the reduction of the error underlying the GPS receiver and the use of sensors for driving support. The system described by the authors is named CoDrive and provides better precision detection capabilities. This system uses the Differential Evolution method to find new positions for all cars, reporting reduced errors.
Qiu and Shen [19]	The authors developed a system that intends to solve the problem of the speed oscillations of the vehicles, increasing the consumption. This system combines the location and velocity variables to optimize the driving, allowing the maintenance of the speed in longer distances and the reduction of consumption. For this purpose, the authors formulate the Collision-Aware vehicle Energy consumption Minimization (CAEM) problem that calculates the optimal velocity profiles which avoid vehicle collision. They implemented the constant velocity principle, implemented an LSMap, and implemented methods to avoid collisions.
Celesti et al. [20]	The authors developed a system to store a large amount of data using the concept of the Internet of Things with a server hosted in the cloud, allowing the people to access them in real-time. Thus, they have information from other traffic peaks accidents and, in this way, they can manage to avoid. Sensors housed in the vehicles and mobile devices do the communication of the incidents. They implemented an OpenGTS server, reporting lower delays.
Al Mamun et al. [21]	The authors developed a mobile system for the collection of traffic data and conditions of a certain location using a smartphone, sending them to the nearest server for further processing. The authors implemented the K-means clustering method with the following features: the speeds of current, previous and next rows and row after the next row, threshold of speed and moderate and highly accident areas, z-axis value of current row of accelerometer, maximum and minimum thresholds for z-axis of accelerometer, and number of total accidents in individual area. They detect Potholes, speed breaker/bumps, and accidents with better accuracy than others.
Guo et al. [22]	The authors developed a mobile system that takes advantage of the aggregated power of passengers to identify and improve the detection of extreme behavior of driving public transport. The system also allows automatic identification of the vehicle's location and the history of locations in terms of accidents. The authors implemented a method to identify the position of the passengers with the Bayesian voting method. The method used the following features: mean wavelength, extreme value, standard deviation, variance, root mean square, skewness, correlation coefficient, an average of amplitude area and energy consumption of acceleration, and the average amplitude area and energy consumption of angular velocity. The method reported an accuracy of about 90%.

Table 3. *Cont.*

Study	Outcomes
Bagheri et al. [23]	The authors developed a system to predict any hole in the pavement of a road. The system is based on a mobile application, sending the geolocation information to the cloud. The data sent to the cloud is used to predict accidents and sends collision warnings to vehicles and pedestrians. The proposed method is the energy-efficient adaptive multimode (AMM) approach. The system as high precision for collision avoidance, increasing the battery life.
Bahadoor and Hosein [24]	The authors developed a new method to facilitate the driving and to help in the energy consumption of the vehicles, detecting negative driving along with social and gamification techniques. The project, named Drive, is composed of a mobile application to acquire different data. It implements a K-means clustering approach on geographical latitude and longitude data. One of the implemented features was the Inter-quartile range, calculating the difference between the 75th and 25th percentiles. Based on the user's rating, the majority of 67% considered the system as useful.
Kwak et al. [25]	The authors developed a system based on cloud computing for route planning, where traffic images are shared through onboard cameras and allow drivers to share traffic information. The system proposed is named as Social Vehicular Navigation (SVN). The method used the short-time events, which increases in traffic communications in congested areas, and data annotation as features.
Laubis et al. [26]	The authors developed a real-time system that allows storing data related to car traffic, road works, or pavement problems to inform the driver with a mobile application. The authors also try to avoid sudden speed reductions that may cause accidents. The authors implemented a Vehicle Operating Cost Model.
Savera et al. [27]	The authors developed a mobile application for the city of Karachi to identify obstacles on the road, road works, and traffic signals to alert the driver and promote a reaction before encounter road problems. The developed model used the Support Vector Machine method with the following inputs: Standard deviation, Number of Mean Crossings, Maximum Mean Crossing Interval, Ratio of the Standard Deviation of current to the previous window, and Ratio of the Standard Deviation of current to next window. The model shows a minimum accuracy of 70%.
Tak et al. [28]	The authors proposed a collision alert system that uses integrated macro-microscopic data and microscopic data, loop detectors, and smartphones, respectively. The proposed system simulated an actual vehicle trip. They used the speed, acceleration, distance between vehicles, and length of the vehicle of the vehicles on the road, implementing a data fusion method. The reported accuracy is similar to the ideal collision warning system in theory.
Aung and Naing [29]	The authors developed a system to detect mainly the traffic condition detection, analyzing the behaviour of the vehicle mainly based on historical data of mobile phones and GPS receiver. The system is composed of the client and the cloud server. On the client-side, the system distinguishes whether a telephone operator is using a vehicle or walking. The authors implemented the Average Motion Filtration method for the classification. On the server-side, it detects the traffic status based on checking the behaviour of the vehicle based on the customer's result by applying the Bayes Classifier. The system reported a mean Square Error (MSE) of 0.330547.

Table 3. *Cont.*

Study	Outcomes
Taha and Nasser [30]	The authors developed a system, which explores the developments made in the detection of vehicles and smartphones using sensors to evaluate the roads so that the individual can know the state of the road. The classification module starts with the fusion and correlation of the data to identify road artefacts, also correlating with the time-of-day, weather, and speed.
Wu et al. [31]	The authors developed a mobile application to verify how and in what way the individual circulates in the urban environment. In the system, the essential requirement is to collect and process large data that raises two critical issues, energy conservation, and scalability. To address the previous question, the GPS standby interval of a smartphone, as well as the speed modes and moving transport, are controlled by the back-end servers in an adaptive real-time way. The authors used the cloud-processing for the detection of transportation modes, reporting low errors.
Basu et al. [32]	The authors developed a mobile system based on the information to predict the route that the individual will make on a given day without thereby compromising the privacy. The implemented method converts the time-sequenced trajectory data into the item-based collaborative filtering (CF) domain. After that, it applies the privacy-preserving CF predictor to obtain predictions for the next location, reporting a mean absolute error between 0.096 and 0.205.
Shi et al. [33]	The authors developed a system based on cloud computing, using a MapReduce aggregation algorithm. The information is collected in several contexts and then aggregated into a single point.
Rodrigues et al. [34]	The authors developed a system for a Massive Multi-Sensor Urban Scanner capable of acquiring large amounts of real-time information from a variety of sources and send them via cloud computing. The purpose of this study consists of the verification of the consumption of each vehicle in a certain route.

3. Results

As illustrated in Figure 1, our review identified 297 scientific publications from the three databases (*i.e.*, IEEE Xplore, ACM Digital Library and ScienceDirect). After the removal of the duplicates, we removed one study. The remaining 296 research papers were evaluated in terms of title, abstract, and keywords, resulting in the exclusion of 165 citations. The evaluation of the full text included only the original research. It excluded scientific reviews, surveys, and studies not directly related to the identification of abnormal situations on the road or traffic. Full-text evaluation of the remaining 131 papers resulted in the exclusion of 113 scientific papers that did not match the defined criteria. The qualitative synthesis and quantitative synthesis included the remaining 18 articles. In summary, our review examined 18 publications.

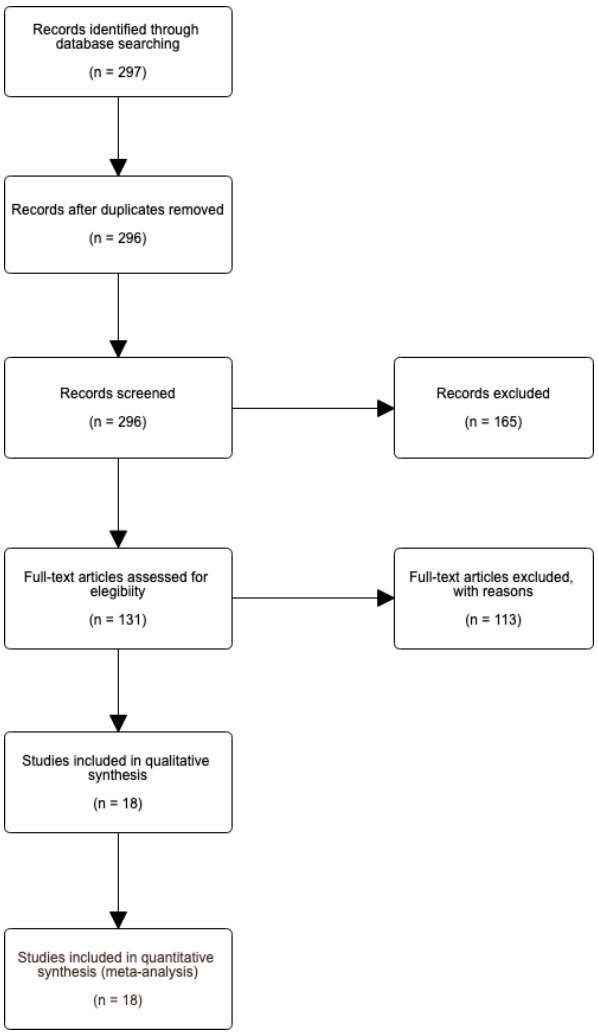

Figure 1. Flow diagram of identification and inclusion of papers.

To obtain more detailed information, we suggest that the interested readers should access the original works cited in this review. Firstly, Table 2 shows the year of publication, publication type, the population used for the research, purpose of the study, sensors used, the availability of raw data and source code allowing the possibility to reproduce the research and the environment of data acquisition. Secondly, Table 3 shows a brief overview of the study. As shown in the Table 2, only four studies (22%) analysed are journal papers. Following the year of publication, we found three studies (17%) published in 2018, three studies (17%) published in 2017, six studies (33%) published in 2016, two studies (11%) published in 2015, two studies (11%) published in 2014, one study (6%) published in 2012, and one study (6%) published in 2011. Regarding the population required for the study, 13 studies (72%) did not provide the number of samples acquired and the population required. Based on the sensors used for data acquisition, all studies used mobile devices with GPS receivers. The availability of the raw data is important to reproduce the results, but only two studies (12%) provided the data acquired publicly, and none of them provided the source code. Finally, related to the environments, nine studies (50%) did not provide the geographic location of the data acquisition.

Moreover, we analyzed the availability of the datasets and the source code used in the different studies returned by the initial query. Following the initial results obtained (293 research articles), only 23 papers (8%) reported the dataset used, and it is available online. In addition, five studies (22%) used the same dataset (KITTI dataset [35]), but none of the studies analyzed used these datasets. Table 4 presents the description of the different datasets used in the literature. In addition, only seven papers (2%) reported the source code used, and it is available online. Finally, Table 5 presents the description of the different source codes used in the literature.

Following the previous tables, the results are categorized according to the different regions of the world, where the data collection was performed. In contrast to the Discussion section, the results are presented without the definition of the geographic place. In the next section, we will associate the country of the first authors to the location of the data acquisition.

Table 4. Dataset analysis of all searched papers.

Studies	Dataset	Description of the Dataset	Included in This Review
[18,36–39]	KITTI dataset [35]	The dataset includes: • Raw and processed grayscale stereo sequences; • Raw and processed color stereo sequences; • 3D Velodyne point clouds; • 3D GPS/IMU data, including location, speed, acceleration, meta information; • Calibration between sensors; • Labelling of the objects.	Yes
[40]	TAPAS Cologne dataset [41]	This dataset describes the traffic within the city of Cologne (Germany) for a whole day.	No
[42]	GeoLife dataset [43]	This dataset includes trajectories, locations and users, and mine the correlation between users and locations in terms of user-generated GPS trajectories.	No
[44]	Dataset available at [45]	This dataset consists in the trajectories of city buses in Seattle, Washington.	No
[46]	Dataset available at [47]	This dataset summarizes the different actions performed with mobile phone, including the Global Positioning System (GPS) data of the user.	No

Table 4. *Cont.*

Studies	Dataset	Description of the Dataset	Included in This Review
[33]	Dataset available at [48]	This dataset includes the data acquired from the sensors available in mobile devices, including cameras, motion sensors and GPS and Web services that can aggregate and interpret the assembled information.	Yes
[49]	Dataset available at [50]	This dataset includes the data available from the sensors available in the mobile devices.	No
[51,52]	Dataset available at [53]	This dataset includes the data acquired from the sensors available in the mobile devices from 85 participants using a representative crowdsensing system that captures approximately 48,000 different place visits.	No
[54]	Dataset available at [55]	It consists in a social network, where the users share their locations.	No
[26]	Dataset available at [56]	It included GPS and camera data about the capture of dynamic events, such as certain snow conditions or other maintenance contract issues.	Yes
[57]	Dataset available at [58]	This dataset contains the retail market basket data from an anonymous Belgian retail store, and traffic accident data.	No
[59]	Dataset available at [60]	It is a community world map that includes different types of data.	No
[61]	Dataset available at [62]	It includes data from various sources, including GPS data of vehicles, real-time traffic data of road cameras, weather data (e.g., temperature or air quality data) from environment sensors and user-generated contents (e.g., tweets, micro-blog, check-ins, and photos) from mobile social applications.	No
[63]	Dataset available at [64]	It includes the data acquired from sensors and the feedback about current interactions.	No
[65]	Dataset available at [66]	This dataset includes the captures of pick-up and drop-off dates/times, pick-up and drop-off locations, trip distances, itemized fares, rate types, payment types, and driver-reported passenger counts.	No
[67]	Dataset available at [68]	It is a dataset of images and annotation, together with standardised evaluation software.	No
[69]	Dataset available at [70]	It is a dataset of 540 fingerprints representing 27 device types.	No
[71]	Data acquired from Twitter and Instagram	It includes the different social networking data acquired from the different users.	No

Table 5. Source code analysis of all searched papers.

Studies	Source Code	Description of the Source Code
[51,72]	CUPUS source code available at [73]	It is a middleware for sensors and sensor networks, which includes semantic models and annotations for representing internet-connected objects, and the results are distributed with cloud computing.
[74]	Source code available at [75]	This platform automates the processing of the different sensors data in order to identify the different car positioning.
[26]	Source code available at [76]	It is a platform to estimate the vehicle costs based on the pavement conditions.
[77]	Source code available at [78] and [79]	These are libraries used to connects and process the different data acquired from the sensors.
[20]	Source code available at [80]	It a a platform to help in track of the positioning of the users.
[81]	Source code available at [82]	It is a library that can be used to process the different data acquired from sensors.

3.1. Studies without the Definition of the Geographic Place for Data Acquisition

In [18], a system named *CoDrive* is composed by two types of cars, including a sensor-rich vehicle and legacy cars. There are a large variety of sensors that can be included in cars, namely the cameras are largely installed in new cars. The sensor-rich vehicle captures more types of data than legacy cars. In addition, legacy cars obtain information from the sensors and combine their information with the data acquired from the sensor-rich car. Some models include a forward radar, a front-facing camera, and multiple ultrasonic sensors in combination with autopilot. Therefore, legacy cars only include traditional GPS for navigation. The CoDrive is commonly a system that implements different sensors to a legacy car. This project uses the smartphone GPS of all drivers RGB-D sensors of sensor-rich cars, and road boundaries of a traffic scene to generate optimization constraints. The algorithm reduces GPS errors to reconstruct traffic scene's aerial view without the requirement of stationary landmarks or 3D maps. Unfortunately, this study lacks information about the number of vehicles used and the particular place or city. The data processing is performed on the cloud, requiring a constant connection to the Internet. The data acquired consist of the data provided by the GPS receiver and inertial sensors. Finally, the authors reported reduced errors with the implementation of the Differential Evolution method.

Qiu and Shen [19] explored the use of the GPS receiver to avoid the collisions, presenting a problem called Collision-Aware vehicle Energy consumption Minimization (CAEM). However, the traditional velocity optimization problem is easier to solve, because CAEM needs that all vehicles present in the study have in mobility to avoid the collision. This study also lacks information about the number of cars used and the particular place or city. The data processing of the data is performed on the cloud, requiring a constant connection to the Internet, and its computational efficiency is abysmal. At the same time as the detection of collisions, the authors try to identify and reduce the speed oscillations that cause the increase of the consumption. This study uses only the GPS data to calculate the distance and velocity of the vehicles. They implemented light schematic map to help identify the green light time interval of each traffic light in the source-destination route of a car, during which the vehicle must drive through the traffic light and methods to avoid collisions. Still, they did not report the accuracy achieved. However, after simulation and real-world testbed experiments, the authors stated that the implemented method had superior performance to other methods.

The authors of [20] installed the mobile traffic sensors, such as the accelerometer, the microphone, and the GPS receiver, in private and public transportation and volunteer vehicles, and they used the data acquired for the prediction of accidents, checking the local and the accident data. This study also lacks information about the number of cars used and the particular place or city. The data processing is

performed on the cloud, requiring a constant connection to the Internet. Thus, the authors used n IoT Cloud system for traffic monitoring and alert notification based on OpenGTS and MongoDB, verifying that it is beneficial for emergency vehicles. The response times of the system allow the reception of alerts in a useful time to avoid the risk of possible accidents.

Bagheri et al. [23] explored the use of the accelerometer and the GPS receiver in smartphones to share information about predictions of collisions. Road safety improves with pedestrian detection using wireless communication because it detects obstructed visibility and adverse weather conditions. Thus, the authors attempt to create a method for vehicle-to-pedestrian (V2P) collision avoidance. The mobile application developed can be adapted to the driver or pedestrian modes, sending the data to the cloud servers. They did not provide the number of samples used for the tests of the mobile application, neither the city or place where the data were acquired. The constants synchronization with the cloud affects mainly the battery time of the mobile devices. The implemented method, named energy-efficient adaptive multimode (AMM) approach, reduces the power consumption with beacon rate control. At the same time, it keeps the data freshness required for timely vehicle-to-pedestrian collision prediction. This method was implemented in the cloud servers, and it changes the frequency of the data acquisition with a mobile application in real time. As a city scale, the authors verified that the implemented method is energy efficient, imposing a small overhead to the battery during the execution of the mobile application. The system shows the feasibility to run on conventional cellular networks and cloud providers with all components of the system. Finally, it handles the prediction of accidents and sends collision warnings, reporting high-precision results.

The authors of [24] developed a mobile application to bridge the gap between negative driving detection and user motivation for safer driving behavior, which acquires the data from the GPS receiver and accelerometer. The authors tested a prototype with a group of six users, but the geographic location was not specified. The authors stated that mobile devices could be used to detect and avoid vehicular accidents. The proposed system, named Drive, includes methods to facilitate driving using social and gamification techniques. The project consists of a mobile application for the relation between negative driving detection and user motivation for safer driving behaviour. For the classification of the different situations, the authors implemented the K-means clustering approach on geographical latitude and longitude data, where the majority of the people consider that the system has benefits. The project includes user motivation and retention strategies, such as gamification and social networking, to promote safe driving. The mobile application has relative success because the users are awarded based on the use of the mobile application.

The Social Vehicular Navigation (SVN), implemented by the authors of [25], is composed of a mobile application that captures the data from the GPS receiver and cameras. Namely, it a vehicular cloud service for route planning implemented in a mobile application for the Android platform. This service is used to share traffic images based on the on-board cameras of the vehicles. In addition, it sends information about road conditions and possible incidents and other visual traffic information named NaviTweets. The different information posted is condensed, and it is presented as a summary of the rout of interest. This information can support route decision making. Unfortunately, this study also lacks the number of cars used and the particular place or city. For the analysis, it makes use of short-time events and data annotation as features.

The authors of [28] used the GPS receiver, accelerometer, and gyroscope for checking and monitoring the risk of collisions based on the distance between two vehicles. Thus, the authors proposed a collision warning system that uses the information of macroscopic and microscopic data, evaluating the different trips of the cars based on NGSIM data. Unfortunately, this study also lacks the number of vehicles used and the particular place or city. They implemented a fusion method with the speed, acceleration, distance between vehicles, and length of the automobiles on the road as features, reporting results similar to the best approach in the literature. For this analysis, the authors compared the results obtained with the results obtained by other collision warning systems. They verified that Infrastructure-based Collision Warning System (ICWS) is not a benefit for the immediate collision

warning system, and Hybrid Collision Warning System (HCWS) produces collision warnings at very similar times to the method proposed. Finally, the authors stated that the distributed computation to each smartphone increases the efficiency of the system.

Wu et al. [31] explores the use of the accelerometer, and WiFi, GSM, and GPS receiver, but the definition of the number of cars and geographic location of the study is unavailable. Mainly, the authors stated that it uses a smartphone to implement a transportation activity survey to research on where and how people travel in an urban area. It consists of the acquisition and process of big data that raises two critical issues, including energy conservation and scalability, to detect transportation modes. Initially, they control the GPS sleeping interval by the back-end server based on the real-time moving speed and transportation modes. Finally, they used MapReduce in the back-end cloud, implementing machine learning algorithms to detect stops and transportation modes, and providing a reliable GPS sleeping interval based on the GPS statistics on the back-end Cloud. Thus, the pain purpose of this authors is to implement the participatory sensing and Cloud-enabled processing system strictly, which incorporates knowledge extracted from the Cloud into sensing control of smartphones, optimizing the sensing control. The results indicate that the system reduces the energy consumption of smartphones and efficiently processes concurrent data from sensors.

The authors of [33] collected data from GPS receiver, microphone, and accelerometer in an undetermined number of cars and geographic location. This study proposes a system that collects the data from a different sensor and sends them to the cloud. For this purpose, the authors also implemented a MapReduce model for mapping the points of warning situations. Finally, the authors proposed a large-scale context management framework with a context aggregation algorithm. Finally, the authors implemented a system for real-time traffic demo, but they did not report the accuracy of the system.

3.2. Studies Performed in Europe

Due to the discomfort caused by the road pavement conditions in the daily lives of driver and passengers, the authors of [17] proposed a system to detect, identify, and manage the different road abnormalities with the data acquired from the sensors available in a smartphone, including the GPS receiver and the accelerometer. The data processing is performed on the cloud, requiring a constant connection to the Internet. The authors conducted the tests in the city of Braga, Portugal, with an 'iOttie Easy One Touch 3' mounted in three cars. The system reported the identification of 4611 anomaly records. Thus, 3450 are not anomalies, 158 are maintenance holes, 563 are short bumps, 434 are long bumps, and 6 are part of an unspecified class. Finally, the proposed system combined Collaborative Mobile Sensing and data-mining approaches for the identification, detection and management of the road abnormalities.

Based on the accelerometer and GPS receiver data, in [26], the authors proposed a method to perform a correlation between the costs of the vehicle, maintenance, consumption, and the history of incidents. The data acquisition was conducted in 2014 by an indeterminate number of cars in Sweden. In addition, the system implements a Vehicle Operating Cost Model to store data related to car traffic, road works, or pavement problems. For the panning of the routes, the quantifies the monetary impact of the road roughness data based on a crowd-based data source and a vehicle cost model. The cost savings depends on vehicle type and the fuel costs, but the leading cause consists in the number of road segments with high roughness index.

In [32], only the data acquired from the GPS receiver available in off-the-shelf mobile devices were used for the implementation of a method to convert a time-sequenced trajectory data into the item-based collaborative filtering (CF) domain. The data acquired from the mobile devices are anonymised and used only to map the different regions. Thus, based on the application of a privacy-preserving and next location prediction, the authors proposed a method to represent the trajectory in the CF domain. The data are always sent to the cloud and composed in two datasets, such as a dataset composed the analysis with 2104 independent trajectories, 12 unique locations and

19,515 data points, and another dataset with 28,340 separate paths, 1334 specific areas, and 593,044 data points, collected in the Italian cities of Pisa and Milan, reported a mean absolute error between 0.096 and 0.205.

In [34], the authors created a system with data acquired from the GPS receiver, accelerometer, and microphone available in mobile devices, in which the data were obtained and tested in Oporto, Portugal. The authors created a system for a Massive Multi-Sensor Urban Scanner capable of acquiring large amounts of real-time information from a variety of sources and send them via cloud computing for the verification of the consumption of each vehicle in a specific route. Based on the data acquired from the smartphones in real-time, it is possible to improve the traffic flow, reduce carbon emissions and promote multi-modal mobility and enhanced coordination among public transit systems.

3.3. Studies Performed in Asia

The authors of [21] used several sensors, such as accelerometer, compass, GPS receiver, and proximity sensor, available in the mobile device to collect all data and send them to its nearest IoT-Fog server for processing the data quickly. The authors did not report the size of the sample of vehicles for the test, but they said that the data acquisition occurred in Aftab Nagar in Dhaka city. The IoT-based system developed analyzes and detects possible problems related to braking, bumps, and automobile traffic for providing safe driving. The system shows the road conditions to the driver. The authors implemented the K-means clustering method with the speeds of current row, previous row, next row and row after the next row, baseline of velocity, accelerometer z-axis value of current row, maximum and minimum points for accelerometer z-axis, threshold for moderate and highly accident areas, and number of total accidents in individual place. The method is implemented to find the location of road abnormalities and accident areas. Finally, the authors stated that this method reports better accuracy than others in the detection of different problems.

Due to the inexistence of studies that considers the phone's relative positions in the vehicle nor the phone's placements, the authors of [22] proposed a system named Crowdsafe that takes into account the smartphone of the passengers for the detection of extreme driving behaviours in public transports. This study intends to research the identification of the impact of different in-vehicle locations on the performance for different strict driving behaviour detection. The data acquisition was performed by 20 students with their smartphones in buses or cars, travelling in public transportation in China. The data acquired include the data of the accelerometer, gyroscope, and GPS receiver, implementing the Bayesian voting method. For the classification of the different situations, the authors used the following features: the mean wavelength, the extreme value, the standard deviation, the variance, the root mean square, the skewness, the correlation coefficient and the averages of amplitude area and energy consumption of acceleration and angular velocity. Thus, they implemented methods based on the Bayesian voting theory to discretize the different situations from various passengers. In general, the system reported an accuracy of about 90%. This accuracy is influenced by the position of the smartphones of the passengers.

Due to the high prevalence of road accidents over the world, Savera et al. [27] used the accelerometer and GPS receiver for the implementation of a mobile application to detect possible breaking and obstacles. Thus, the significant driving problems are related to speed breakers and ditches, causing high causalities due to no warning signs, lack of street lights, and substandard construction. Thus, this study implements an Android application, and the experimental procedure was in the city of Karachi to detect upcoming speed breakers and ditches within a 10-12 meter radius. The authors implemented the Support Vector Machine (SVM), which has been trained with data from multiple devices. The features used are the Standard deviation, Number of Mean Crossings, Maximum Mean Crossing Interval, Ratio of the Standard Deviation of current to the previous window, and Ratio of the Standard Deviation of current to next window, reporting a minimum overall accuracy of 70%. However, the prediction of speed breakers and ditches says an accuracy up to 85% with minimal power consumption.

In [30], the authors implement and test a framework to enable safety-based alerts and road navigation, and recognize road conditions in the roads of Saudi Arabia. The authors make use of the accelerometer and GPS receiver available in mobile devices to detecting traffic condition by analyzing the behavior of the vehicle. The framework fuses and correlates the sensors' data with the time-of-day, weather, and speed to identify road artefacts. The system has two parts, where the mobile phone realizes the identification of taking a vehicle or walking activities with the average moving filtering method, and the cloud server achieves the detection of the traffic status with Bayes classifier.

3.4. Studies Performed in Africa

The authors of [29] used the data acquired from the GPS receiver and the history data to detect traffic conditions by analyzing the behaviour of the vehicle primarily. The tests were performed on the road between Baham Campus to Hlaing Campus and Insein road by one car. The authors presented an architecture that accesses to the vehicle's CAN-Bus through an OBDII connector to promote safe driving. The system starts with the identification of the use of a car or walking using the average motion filtration method. In the next stage, the authors applied the Bayesian classifier in the cloud for the identification of the traffic status based on checking the behaviour of the vehicle based on the customer's result. Thus, the authors detected road conditions, including potholes, speed bumps, and slowdowns, providing information about the quality of the road to the drivers. It reports a Mean Square Error (MSE) of 0.330547.

4. Discussion

The use of sensors embedded in mobile devices for the identification of warning situations during driving and road abnormalities using cloud computing is a topic that is not widely studied. Some studies analyzed in this review are not directly related to the subject, but it matches the purpose with the mapping of the vehicles' location. However, these studies lack the discussion of some problems related to the security and privacy of the individuals.

The majority of the publications available about this subject are mainly conference papers, which indicates that the studies analyzed are related to a non-validated small prototype or ongoing projects in an early stage.

Commonly, several studies did not present the datasets used in the different research works analyzed are not publicly available, and the details about the implementation. In addition, the source code of the application of the various techniques is not publicly available. Thus, it disallows the reproducibility of the results of the studies by other authors. Following these problems, we requested the access of source code and datasets to the different authors.

Following the use of the different sensors available on mobile devices, the GPS receiver is used in all studies to map the different warning situations or road problems. According to the classification of the sensors available in mobile devices presented in [83], 15 of 18 scientific articles (83%) taken into account the use of inertial sensors combined with the use of the GPS receiver. In addition, one of the research works (6%) used imaging/video sensors combined with the GPS receiver, and three of the studies (17%) used acoustic sensors fused with the data acquired from the GPS receiver.

Following the details about the data acquisition available in the different studies, nine studies (50%) did not present the geographic location of the data acquisition. It would be interesting to map the regions with a significant number of warning situations, several adverse road conditions, or the amount of authors studying this subject.

As several studies did not provide the location of the experimental procedures, the country of the first author was considered as the place of the data acquisition. Based on the countries of the experiments and data acquisition of the different studies presented in Figure 2, the geographic regions with more research works are North America, Southwest of Europe, and an area of the Republic of China.

Figure 2. Dispersion of the different studies by region.

As previously presented, the primary purpose of this review is to implement a system for the detection of warning situations. The experiments will be related to the driving style or adverse road condition in the Centre region of Portugal. Thus, with this review, we found two studies (11%) related to this subject performed or ongoing in the North region of Portugal.

This review cannot be compared with other studies, because there are only a few literature reviews that are not directly related to our purpose. Only one review [84] includes our research, but it does not present the research keywords and methodology.

Based on the research studies analyzed, 12 research works (67%) did not present the sample size used for the creation and test of the different methods. In addition, none of the studies analyzed shows statistical significance. It could be a problem because the reliability of the system and the accuracies presented cannot be statistically validated and generalized for future studies. However, accuracy is unavailable in 13 research works (72%) analyzed.

Based on the analysed studies, we present, in Table 6, the pros and cons of each study. In general, we found that the significant benefits of the different systems are centred in the monitoring of abnormal situations, obstacles, and road conditions with the various sensors available in the mobile devices. However, the major problem found is the need for a constant Internet connection to store and access the data available in the cloud. The issues with battery lifetime are recently analysed, adopting methods for the reduction of the overhead during the data acquisition. With the use of cloud processing, the benefits of the system are related to the possibility to perform high power processing tasks.

Table 6. Pros and cons of the studies analysed.

Studies	Pros	Cons
Soares et al. [17]	The authors developed a method that integrates different components for the detection of road conditions in non-controlled environments; They identified the design problems of the platform, and they improved it to detect the different abnormalities in the road; The authors prevented the influence of user-generated data redundancy and imprecision on positioning data.	Incorrect information acquired from GPS receiver; Different results were achieved with different positions of the mobile device; The need for a constant Internet connection; the crowdsourcing model has uncontrolled conditions.
Demetriou et al. [18]	The authors corrected GPS errors; The system uses the GPS receivers of mobile phones, RGB-D sensors of sensor-rich cars, and road boundaries of a traffic scene; The system generated optimization constraints; The system reduces the GPS errors and reconstructs the traffic scene's aerial view; It does not require stationary landmarks and 3D maps; The authors improved the detection of outdoor positioning of all participating cars, combining distance, angle, and visual information in a unique way; It uses the existing sensing capabilities of cars as moving landmarks; A real-world evaluation was performed.	It requires the participation of at least one sensor-rich car; the need for a constant Internet connection.
Qiu and Shen [19]	The system attempts to reduce the energy consumption, building a light schematic map; The authors calculated the vehicle's velocity to prevent collisions between vehicles.	The authors need to improve the optimization of the velocity; the authors should consider collisions between vehicles in the different route segments; the need for a constant Internet connection.
Celesti et al. [20]	The implemented system is flexible and scalable; It allows to cover a wide area of the city; It can use the common 4G network; The system is not expensive; It is important for drivers of critical rescue vehicles; It presents useful messages to avoid the accidents at acceptable response times.	The need for a constant Internet connection; the authors need to analyse the impacts of the security.
Al Mamun et al. [21]	The proposed model for safe driving includes a fog and cluster architecture; The system informs about accidents and overall road condition; The longitude, latitude, speed and acceleration data of vehicles were acquired for clustering; The clustering is used to detect potholes, speed breakers, bumps, and real-time accident on the road; Cloud is used to sync fog information.	Fog has limited memory; the early prediction of an accident should be performed; the suggestion of safe path should be implemented; the suggestion of path that consumes less time to ride should be implemented; the need of a constant Internet connection.

Table 6. *Cont.*

Studies	Pros	Cons
Guo et al. [22]	The authors developed a system for the identification of extreme driving behaviours on public transports; It understands the location and behavior contexts of a passenger with smartphone sensing; Using multi-sensor technologies, it detects extreme driving behaviours in a public vehicle; The authors used Bayesian voting to solve the problems related to the mobile device positioning; The accuracy of the detection of extreme driving behavior is improved.	The need of a constant Internet connection; The authors should be analyzing the different places as parts; The position of the mobile device should be better explained; The system should be adapted to the location of the mobile device; The authors should combine the results with the results obtained by other authors.
Bagheri et al. [23]	A wireless-based pedestrian road safety system only has a small overhead in the battery lifetime; The use of geolocation does not practically affect the battery lifetime; The use of non-adaptive methods increases the battery lifetime; The computation load and estimated costs shows that the systems are feasible to run in conventional cloud providers; The systems can run over traditional cellular networks.	The constant connection to the cloud may reduce the battery lifetime quickly, making the system impractical; the need for a continuous Internet connection.
Bahadoor and Hosein [24]	The mobile application employs user motivation and retention strategies to promote safe driving; An interactive map shows the points of interest and positive driving areas; The positive driving is rewarded.	The weather data are included as negative drive detection; the system does not integrate some mobile sensors, such as the gyroscope and the magnetic compass; only a future release consists of the user monitoring feature; the monitoring of driving behaviour of friends will be included in the future; the use of a social feed will be included in a future version.
Kwak et al. [25]	The authors presented the system design; The authors implemented a prototype that is running on the Android smartphone platform; It exploits the mobility of vehicles to expand coverage beyond the limited scope of static sensors; The system shows images related to the traffic conditions on the alternative routes ahead.	The system has limitations to taking semantically rich information into account to support decision making and improve satisfaction in route selection; the problem of sending the contexts to the cloud; the synchronization of the data acquisition and processing; the need of a constant Internet connection.
Laubis et al. [26]	The determination of the extension of a bypassing of rough road segments is possible; The chosen baseline scenarios are more realistic; The results show potential yearly cost savings for different car types and road roughness levels; The presentation of a dependency between fuel price and overall cost savings; The main factor is the number of road segments with high roughness index.	The determination of the potential reduction of international roughness index would determine the actual savings potential more realistically; the determination of cost savings potential by rerouting to roads with low international roughness index should be done; the time spent should be considered; the results related to the savings should be more analysed; the need of a constant Internet connection.

Table 6. *Cont.*

Studies	Pros	Cons
Savera et al. [27]	The architecture presented for a detection system can be used in any location; The data collection for the vehicle movement is independent of the position of the mobile device; The created method alert users ahead of time-based on a distance threshold; The system uses a cloud infrastructure to receive and store all GPS data; The speed breakers or ditches can be added or removed from the data; The system can differentiate speed breakers and ditches with the sensors available in a mobile device; The mobile application has low power consumption; The mobile application	The distinction of speed breakers and ditches should be more worked; if the mobile device is positioned and oriented to left, the mobile application is not able to distinguish speed breakers and ditches with a high degree of accuracy; the inaccuracy of the GPS receiver; the exact location of speed breakers and ditches cannot always be detected; the need of a constant Internet connection.
Tak et al. [28]	Vehicle communication-based Collision Warning System (VCWS) and Hybrid Collision Warning System (HCWS) produce collision warnings at very similar times; The HCWS can be applied to existing systems with a small additional cost; The efficiency of the system increases with computation resources and load distributed to each mobile device.	Infrastructure-based Collision Warning System (ICWS) is inadequate for immediate collision warning system; it requires high market penetration rate; it requires high cost for installation rate; it lacks the traffic information for large areas; the need of a constant Internet connection.
Aung and Naing [29]	The system predicts the current traffic status by watching the available vehicles with few GPS receivers; The system implements the Bayes classifier to obtain better results; The system identifies if the phone is in a vehicle or walking.	The handling and scheduling all incoming Mobile device data for improving processing time on Server side needs more research; If only one vehicle submits the sensors data to the server, the system cannot detect the current situation perfectly; the problem of sending the contexts to the cloud; the need of a constant Internet connection.
Taha and Nasser [30]	The proposed framework is extendable; The service application provides drivers with Quality of Road (QoR) status; The framework enables safety-based alerts and road navigation; The framework recognizes road conditions; The data processing is performed in the cloud and locally in the mobile device; It recognizes road features to enhance safe driving.	The prototype needs more validation and testing; the problem of sending the contexts to the cloud; he synchronization of the data acquisition and processing; the need for a constant Internet connection.
Wu et al. [31]	The energy consumption of mobile devices is efficiently reduced; Capability to process concurrent data from many users; Collects data from the accelerometer sensor every 500ms; Detects the ambient of Wi-Fi signals every 30 seconds; Detects the user status; Enable the GPS power-saving; Collects location intensive data; Filter the data acquired.	The problem of sending the contexts to the cloud; the synchronization of the data acquisition and processing; the need for a constant Internet connection.

Table 6. *Cont.*

Studies	Pros	Cons
Basu et al. [32]	The method converts the time-sequenced trajectory data into the item-based collaborative filtering (CF) domain; It is implemented a privacy-preserving CF predictor to obtain predictions for next location; The developed model with anonymised trajectory data has better predictive power for denser datasets with short trajectories than more sparse datasets with longer trajectories; The model works better with denser datasets with shorter trajectories; The average prediction times may decrease with the trajectory-level concurrency turned-off; The computational performance with encrypted data is reasonable; The predictive power of the developed model for dense datasets containing short trajectories is accurate.	The model should protect the privacy of the individual vertices; The model should consider the various context sensitivities in next location recommendation; the model should be tested with other public trajectory datasets; the model should be tested in privacy-preserving prediction with non-CF prediction models; the problem of energy consumption on the mobile devices while collecting and sending the contexts to the cloud; the need of a constant Internet connection; the model reports bad results with sparse datasets containing longer trajectories; when compared with Jacob Nielsen recommendation, the prediction time is bad.
Shi et al. [33]	The information aggregated from many contexts reflect the status of the real world; Based on the context, the developers can design interesting and useful mobile applications; Collection and aggregation of large-scale contexts to form the context situation; The model uniformly collects the contexts and send them to the cloud; The use of MapReduce computing paradigm allows the performance of real-time and large-scale context handling; A prototype of a framework for a large-scale context management was designed; The validity of the framework was verified with the implementation of real-time traffic demo.	It needs the performance optimization of the context aggregation process; The problem of energy consumption on the mobile devices while collecting and sending the contexts to the cloud; The need for a constant Internet connection.
Rodrigues et al. [34]	Capability of the acquisition of large quantities of real-time information from a vast variety of sources; capability to send data to a cloud server with multiple connection interfaces; capability for a real-time traffic estimation; correlation of fuel consumption, speed and vehicle trajectory with the proposed system; capability of real-time estimation of energy efficiency and carbon; Capability of the estimation of the emissions: Capability to optimize the multi-modal route; capability to send personalized mobility recommendations; capability to expand citizen information; capability to integrate various classes of sensors; it has a tiered back-end server structure; It is scalable and transparent to accommodate large numbers of heterogeneous information sources.	The number of queries per second allowed by the OBD devices is variable; the sampling rate of sensors is low; the request of very high storage capacity; the need of a constant Internet connection; the battery of the mobile devices is meagre.

These systems could be an advantage for the drivers to know the road problems before the user choose the route. Still, it should be scientifically and statistically validated before generalized use by the population.

5. Conclusions

This review identified the studies related to the identification of warning situations, road problems, driving behaviour implemented with the use of cloud computing. In addition, these studies use the data acquired from the sensors available on mobile devices. We examined 18 studies, and the main finding is the following:

- (RQ1) Cloud computing can be used to store a large amount of data acquired from the sensors available in mobile devices anywhere at any time. It provides capabilities for the processing of a large volume of data in server-side with low delays in the obtaining of the results;
- (RQ2) The traffic management can make use of the data acquired from all sensors available on mobile devices. However, the most important is the GPS receiver that allows the mapping of the driving activities. However, the inertial sensors, *i.e.*, accelerometer and gyroscope, the magnetic sensors, *i.e.*, magnetometer and compass, the acoustic sensors, *i.e.*, microphone, and imaging sensors, *i.e.*, camera, are useful for the recognition of different warning situations handling the automatic recognition of them;
- (RQ3) The sensors available in mobile devices allow the recognition of the geographic location of the vehicle, and different road situations, including braking, bumps, maintenance holes, and other data labelled by the user.

This review has taken into account 297 scientific publications available in three databases, such as IEEE Xplore, ACM Digital Library, and ScienceDirect. Firstly, we excluded the duplicates from the analysis. After that, based on the title and abstract, several studies have also been eliminated. Finally, the exclusion was performed by the content, resulting in the qualitative and quantitative analysis of 18 papers.

Since the authors did not share the source code of the methods, and the datasets, the replication of the studies is not possible. Secondly, the studies analyzed did not present data related to the statistic validation, where the major part of the works examined were conference papers. All scientific research studies were taken into account the use of the GPS receiver. However, there is a relevant focus on the use of inertial sensors because it handles the recognition of different types of movement or vibration.

As future work, we will design and develop a system for the detection of different warning situations and driving behavior in the Centre region of Portugal.

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