



Vehicle Detection and Traffic Estimation with Sensors Technologies for Intelligent Transportation Systems

Pankaj P. Tasgaonkar¹ · Rahul Dev Garg¹ · Pradeep Kumar Garg¹

Received: 25 February 2020 / Revised: 20 April 2020 / Published online: 24 June 2020
© Springer Science+Business Media, LLC, part of Springer Nature 2020

Abstract

The paper reviews the vehicle detection methods using the intrusive and non-intrusive sensors. The objective of literature review is to summarize the sensors and technologies used in vehicle detection and traffic estimation. Integrating these sensors will give vital information by communicating with the monitoring station related to the presence of the vehicle on the road. Sensors and communicating technologies have a widespread application in intelligent transportation systems. The modern devices and technologies are discussed that determine the vehicle count, classification, location, speed, traffic volume, density, traffic estimation. Sensors fusion can further integrate information from different sources and provides more accuracy.

Keywords Sensors · GPS · WSN · Intelligent transportation system (ITS) · Vehicle detection · Vehicle classification

1 Introduction

Sensors and other technologies obtain information related to the physical attributes of the environment or system. Sensors can vary from small size to bulky one as per the application. Sensors have a vast number of applications in agriculture, defence, environment, forest, disaster management, medical, and transportation, etc. [1]. One of the important uses is in the Intelligent Transportation System (ITS) which consists of electronics, communications, control, and sensing all types of traffic parameters to improve efficiency through the intrusive or non-intrusive sensors [7]. The sensors provide the traffic-related information, like speed, volume, density, individual classification of the vehicles, and much more.

The road transport has a crucial role in the economic growth. Public transportation is available almost in all the countries; however, people prefer their motorbikes or cars for commuting, but it leads to a rise in the number of vehicles and pollution

✉ Pankaj P. Tasgaonkar
pankajtgr@ce.iitr.ac.in

¹ Civil Engineering Department, Indian Institute of Technology, Roorkee, Roorkee, India

on the road. During peak hours, lots of congestion is faced by the drivers. The commuters and goods transport occupy the entire width of way for faster travel to the destination. The monitoring of road vehicles is possible with the help of modern devices and technologies [19]. Installations of cameras and various sensors along the road can detect the presence of vehicles, while a real-time Global Positioning System (GPS) can track the vehicle throughout the journey [4]. Vehicle detection is also based on image and video processing by using static and dynamic cameras [78].

The traffic parameters are used to determine the road traffic conditions, i.e., whether the road is free for travel or is congested [8]. The traffic congestions may also be due to rains, snowfall, water-logging, landslides, accidents, oil spill on the road, big container vehicles blocking the roads, new road lane construction, agitation, strikes, and religious activities. All these events have a massive effect on road traffic in the city and national highway [44]. The traditional methods of traffic monitoring comprise of the intrusive sensors, like inductive loops, pneumatic tubes, piezoelectric sensors. However, these equipment are bulky, and maintenance is quite tricky as road pavement cut is required to install them [19], and the traffic is adversely affected due to installation work.

A literature study was carried out on vehicle detection, i.e., sensors and technologies available for detection of vehicles. To determine the papers related with the congestion on roads, papers based on traffic estimation were referred. Various search engines e.g. Google Scholar, Science Direct, Microsoft Academic, CORE, etc. have been used in order to get the research papers most relevant to the current topic. This paper discusses the popularly available vehicle detection and tracking systems, including an overview of various sensors and technologies used for vehicle detection, road traffic monitoring, and management. Numerous case studies using sensor technologies are also covered. At the end, the readers will get a reasonably good idea about the selection and use of sensors/technology for a specific application of ITS. The paper is organised in six different sections. Section 1 covers the introductory part, while Sect. 2 covers the various vehicle detection systems and their needs. Section 3 includes several applications of vehicle tracking systems, while Sect. 4 focuses on selected case studies of vehicle detection and traffic estimation. Section 5 presents a comparative study of sensors technologies for transportation system, while Sect. 6 summarises the review of work.

2 Vehicle Detection Systems

The vehicle detection system gives detailed information about the type of vehicle, whether it is a car, truck, bus, or heavy vehicle. The driver details can also be saved and shared through the server. The speed and traffic are estimated to avoid speed violations and traffic congestion by giving alerts to drivers. Drivers get the alarms so they can avoid congestion or reduce the speed or take the alternate path available on the route. Present-day sensors, like accelerometers [37, 56], ultrasonic [24], magnetic sensors [64] are useful in vehicle classification, distance measurement and determining the vehicle speed. The radio frequency identification (RFID) [69] is frequently being used for tracking the vehicles at certain checkpoints. The

RFID readers [46] are installed on the roadside to monitor the information related to the vehicle and compare it to calculate the speed travelled for a particular distance. The RFID with the combination of hybrid technologies [45], like Geographic Information System (GIS) and Wireless Sensor Network (WSN), [72], Global System for Mobile (GSM) [42], GPS [58] are minimizing the disadvantages of RFID and increasing the efficiency for many ITS applications. Video cameras [57], High-resolution satellite images [13]; Wang et al., 2013), Unmanned Aerial Vehicles (UAVs) Aerial images [15], Light Detection and Ranging (LiDAR) [51] based systems are also used, but these have a higher cost as compared to other methods, like WSN [11, 43], and GIS [5, 14].

The sensor nodes collect the data related to road transport. This sensor is low-cost and works on battery backup and communicates wirelessly to the devices. This information will decrease the time required for traveling, pollution in the air, overall consumption of fuel, and the congestion on roads [66]. Various types of sensors have been used world-wide for traffic-related studies. The two broad categories are; intrusive and non-intrusive sensors, as briefly explained below:

2.1 Intrusive Sensors

These include inductive loops [8] (Marszalek et al. 2018), magnetometers [68, 79], piezoelectric sensors [8], micro loop probes and pneumatic road tubes. The sensors are installed beneath the pavement of the road. These sensors provide high accuracy for vehicle detection [19]; but the disadvantage is that road cutting requires closure of the way.

2.2 Non-intrusive Sensors

These are installed above ground, and include video cameras [78], microwave radar [210], LiDAR [36], ultrasonic [27, 35] and hybrid sensor technologies, like passive infrared [47]. These sensors are installed beside the roadside or overhead of the lane. These devices detect the presence, speed, classify the types of vehicles, lane crossing, etc. The most significant disadvantage is that they are power-hungry devices, and their performance deteriorates during fog, heavy snow, or rains.

The vehicle tracking system consists of grouping GPSs, RFID tags, readers, and sensors. The GPS is a tracking device that determines the exact location of a vehicle [20]. The collected data from the sensor/device is sent to the server through GSM/General Packet Radio Service (GPRS) module installed in the GPS unit. The reader reads the information from the RFID tag, and GIS traces the location of the vehicle. The GPS works on the constellation of satellites in the space that computes the position on the Earth [39]. It has an enormous number of applications in transportation, like (1) vehicle fleet management and monitoring, (2) data collection and mapping of the transport infrastructure, (3) incident management and monitoring, and (4) vehicle navigation systems.

3 Applications of Vehicle Tracking Systems

The GPS tracking is a vital technology in day-to-day life. Many organizations and services require real-time monitoring of the vehicles. It is a way to find out the location of objects, persons or vehicles, its source, and destination. The tracking devices trace the path of the vehicle. The vehicle tracking system provides detailed information regarding latitude, longitude, and direction of flow of vehicle from source to destination. If a vehicle is stolen or damaged during an accident; in those cases, tracking devices can provide vital information about the vehicle through the server to the monitoring station. The tracking may be in the form of Barcode, Quick response (QR) code, RFID based, or GPS based tracking. Some of the important applications of the tracking system are as follows:-

3.1 Tracking Criminals

Police officers can install a GPS tracker for the suspected vehicle. The device can monitor every move and direction of the vehicle. The GPS devices track the vehicles continuously, and can help police to track any stolen or missing vehicles [39] and criminals. In developed countries, along with GPS tracking, video surveillance from the helicopters keeps a track of the criminals, informs the chasing vehicles to follow the direction so that they catch them quickly.

3.2 School Buses

The tracking devices installed in the school buses will give the current location and the distance from the school to home and vice versa [41]. This information is valuable as regards to child safety in the vehicle. Schools, as well as parents with the app installed on their smartphone can track the status of the school buses. Cameras are also installed in school buses for real-time video surveillance.

3.3 Bus Rapid Transit Systems (BRTS)

In BRTS, a separate lane is allocated, especially for the city buses. It gives priority to city buses at intersections, and diversions, The city buses can interact with each other to reduce the delays [21]. The display board indicates the information about all the bus running on the route, its predicted time of arrival, and the last stop to the passengers.

3.4 Cabs

Commuters use private cars for a shorter or outstation journey from companies, like OLA, UBER, MERU, etc. These offers this facility with various types of cars, like mini, micro, sedan, prime, etc., based on the economy and comfort of the passengers.

Three to four passengers on the same route can share the car through pool options. The mobile application on the smartphone gives data of nearby vehicles from the source and estimated time of arrival using the GPS [32]. It indicates the shortest and fastest route from source to destination after hiring the car. The application displays the information of the driver, like his name, contact number, photo, vehicle number, mobile number. In case of an emergency, relatives can also get the details.

3.5 Fleet and Traffic Management

For fleet management, the organizations keep the database of the information and track the transport vehicles traveling throughout the journey. It keeps the information related to the driver, types of goods, its capacity, halt record, etc. It consists of database information, telematics, and GPS tracking [39]. It can help prevent delays in delivery, fuel consumption, reduce road accidents, track and recover lost vehicles.

In case of traffic regulation, the system would provide information to drivers about taking alternate route or release the traffic at regular intervals, as the system is continuously tracking the vehicles during accident or landslides or falling of the vehicle on the road or traffic jam due to heavy rush in a festival.

3.6 Smart Cities

The system will provide reliable navigation and traffic management for the drivers and commuters of the vehicle. It will mitigate traffic congestion with the help of Internet of Things [17]. The monitoring system collects the data and then communicates to the central server. The information is related to weather, disasters, traffic congestion, diversion, bridges, flyovers, etc.

4 Some Case Studies

A large number of studies have been carried out world-wide on vehicle detection and traffic estimation using sensors, electronic devices, cameras, etc. These case studies have been grouped as per sensors/devices used for traffic estimation, vehicle tracking and traffic management. Some of the popular sensors and technologies used are discussed as follows:

4.1 Accelerometers

Accelerometers with the combination of magnetometers detect the traffic conditions. Accelerometers detect the vehicle axles while magnetometers check vehicle entry, exit, and approximate speed. Ma et al. [37] developed a system and tested at Interstate 80 at Pinole, CA, USA. They installed high-resolution cameras on the highway that give the video and images while a commercial weigh-in-motion system records the axle counts, spacing, and weight of every truck. The results obtained include vehicle classification, axle spacing, and vehicle counts. The results during

congestion, were found to be 99% accuracy using the prototype automatic vehicle classification system.

Rivas et al. [56] developed an algorithm to detect the presence of cars, their travel direction, and speed. The piezoelectric accelerometers have the same working principle as Micro-Electromechanical Systems (MEMS), i.e., to examine the peak levels and frequency of vibrations of vehicles through this sensor. A radar and video-camera was used to validate the results with that of accelerometer data.

4.2 Ultrasonic Sensors

Odat et al. [47] used six Passive infrared(PIR) thermopiles Melexis MLX 90614 attached to the system through SMBus. The ultrasonic rangefinder MaxBotix MB 7066 and two passive infrared sensors arrays in combination classified the vehicle types, detected the presence, and estimated their speed. The sensing device interfaced with the microcontroller through serial communication. They measured the temperature in the adjacent area. The ARM Cortex M4 with a frequency of 168 MHz, and an internal Lithium battery of 8 Ah was used as energy source. The passive Infrared (PIR) sensors detected the infrared radiation emitted by any vehicle. The ultrasonic sensors emitted the sound waves and echoes back after recognizing the target. They used a dynamic Bayesian Algorithm that integrates data from different sources in spatial as well as temporal domain. The proposed model having a combined interface of the sensors gave 99% accuracy for vehicle detection, with a mean error of 5 kph in vehicle speed estimation, and a mean error of 0.7 m in vehicle length estimation. The decentralized approach was found to reduce the energy utilization and increase its lifetime.

Jo et al. [26] used ultrasonic sensors module NRF04 from Devantech and MicaZ from Crossbow which detected the vehicles in multiple lanes. The ultrasonic sensors obtained road traffic data with WSNs. This information is sent to the client-server, using a routing protocol for decreasing the power consumption and transmission delay. The vehicle detection algorithm involves segmentation; vector signal conditioning, vector extraction, and pattern matching. The routing protocol consisted of power profiling as well as the discovery phase, synchronization, and data collection. Ultrasonic sensors measured the distance data of the vehicle from two lanes out of the bidirectional four lanes road. The vehicle detection algorithm gave an error rate of less than 2%, and routing protocols saved about 92% of the communication module power.

4.3 Magnetic Sensors

A magnetic sensor recognizes the change in the magnetic field. All vehicles consist of some amount of metals. It creates a magnetic disturbance concerning the Earth's magnetic field. Zhu and Yu [79] developed an algorithm for detecting the cars in parking and determining the speed using WSNs. The proposed algorithm includes state-machine detection and cross-correlation detection. At the same time, cross-correlation gives the speed between the signals of two sensors along the road.

Experimental results showed that the parking algorithm had an accuracy of 99.65% for entry and 99.44% for an exit, while the speed determination had an accuracy of 92%.

Taghvaeeyan and Rajamani [64] used magnetic sensor network along the roadways of the Minnesota which measured the traffic in the immediately adjacent lane. Figure 1 shows the arrangement of sensors, which includes four three-axis Anisotropic Magnetic-Resistive (AMR) sensor placed on the side of the road. The system measured speed, number of vehicles, and differentiated the type of vehicle that was passing through a nearby lane. Signal processing techniques computed faster with the cross correlation techniques. These results show that the maximum error of the speed estimated is less than 2.5% over the entire range of 5–27 m/s (11–60 mi/h).

The algorithm developed by Vancin et al. [67] gives the traffic status of the road in four conditions; no traffic, mild traffic, heavy traffic, and very-heavy traffic. The magnetic sensors obtained immediate, real-time, and novel solutions as a vehicle detection system. The sensor nodes are installed at the start and the finish of the road to obtain the number of vehicles per hour for a day for traffic analysis. The vehicle classification algorithm classified the vehicle, like cars, mini-buses, buses, and trucks by obtaining magnetic signature length with an accuracy rate of 95%.

Velisavljevic et al. [68] installed a set of 32 magnetometer sensor nodes on a public road of the area of Bicester, Oxfordshire, UK. Magnetic sensors generated a magnetic signature of the vehicle. Magnetic signatures determined the vehicle speed, length by extracting the position at the start and the end. The time delay between the two graphs determined the vehicle speed. Video recording and magnetic loop devices validated the results.

4.4 GPS Receivers

The exact location, i.e., latitude, longitude and altitude is determined with the GPS. The GPS uses the basic working principle of trilateration to get relative position of

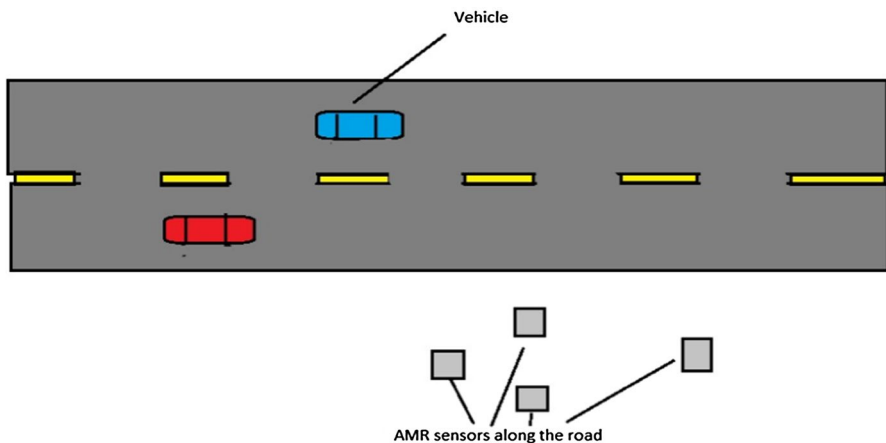


Fig. 1 Magnetic sensor collects data of the vehicle

objects. The GPS receivers are also in built in the smart phone or a mobile computer attached to the car. It can track the movement of the trucks, how the driver delivers the goods timely to its proper destination. Fleet management systems, smartphones, ambulances usually have GPS receivers for tracking or finding the locations [58]. The GPS is a satellite-based system that uses satellites orbiting the globe to measure and compute its position on the Earth. It is also known as Global Navigational Satellite System (GNSS). At least four satellites are required to be tracked by the GPS receiver to improve the accuracy. The Global Positioning System in vehicle tracking systems is used that provide information such as the location coordinates, speed, time. This GPS receiver is used today in many applications, like smartphones, cabs, fleet management, etc. [4]. The GPS uses Geofencing; whenever a vehicle enters a boundary, location-based services get activated by the application. The GSM/GPRS module is useful for maintaining the communication between the computer and GSM/GPRS system installed in the vehicle with a SIM module. A GSM/GPRS module assembles a GSM/GPRS modem with, so that it can be easily interfaced with a computer or a microprocessor/microcontroller-based system interfaces with a GSM/GPRS module through standard communication interfaces, like RS-232 (serial port), USB, etc.

4.5 RFID

The RFID identifies the object and tracks the tag with a reader. The data related to any vehicle is stored electronically on the card. The RFID tags can be active tags or passive tags. Passive tags don't have their power; they get it from the adjacent RFID reader. Active tags have their battery source; they can operate at a longer distance [45]. The RFID technology improves the location accuracy with the arrangement of the RFID tags and the vehicles that carry RFID readers along with them. The GPS accuracy minimizes when the traffic is under the tunnels, basement parking, or dense areas. Figure 2 shows the view of the positioning using active RFID [75]; the

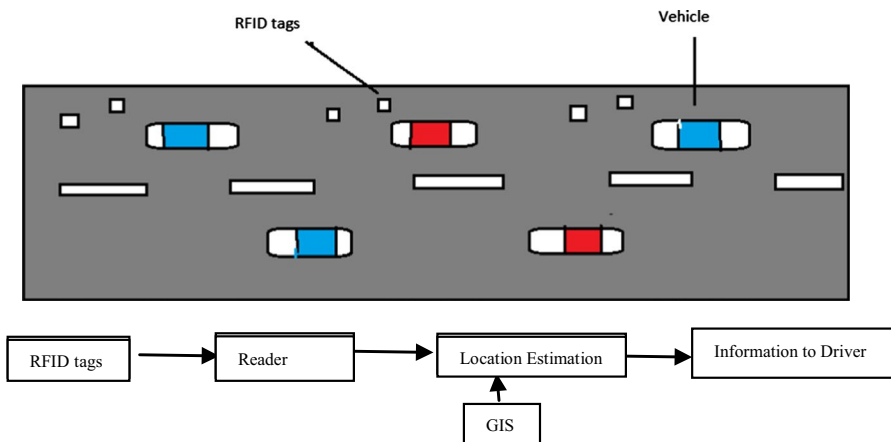


Fig. 2 Active RFID positioning scheme

tags were installed on one lane of the road. The reader reads the information from these cards. The location and speed are determined by tag readings and provided to the GIS-based navigation system. Nearby vehicles get the data through wireless communication. The traffic status, vehicle collision, and shortest route information are thus determined.

The RFID technology can be integrated with WSN to develop an intelligent bus tracking system [21]. The integration is done in two ways. In the first one, with the wireless facility, RFID reader transmits data to and from the reader. The RFID reader behaves like a sensor node; it reads the tag ID of a vehicle and sends it to the host application with an ad-hoc network. In other case, motion sensor detects the change in the direction of the object. The hybrid technique with WSN and RFID offers more benefits as there is more noise during the measurement of Received Signal Strength Indicator (RSSI), while WSN has a good range [12]. On the other hand, RFID technology has the advantage of providing precise information with high frequency (HF) and good range for Ultra High Frequency (UHF). The combination of indoor positioning and tracking system increases the positioning accuracy and availability. Figure 3 shows the architecture of the hybrid positioning system, where the sensor node collects the information along with RFID [72].

The UHF and HF tags have their own RFID reader, while the sensor nodes of WSN communicate through IPV6. The positioning algorithm utilizes the Kalman filter. The information passes through the local area network to the database server. Xiong et al. [72] evaluated the performance of the proposed tracking system, first through simulations and then through real experiment deployment.

Nafar and Shamsi [42] used the RFID and GSM together with IEEE802.15.4 to create a vehicle identification (ID) system. They used the tag and kept a fixed waiting time. Later, a pseudo-random generator was used to add a random number to provide the security. Initially, scanning is done by RFID to avoid collision of the packets. It becomes difficult for the third party to recognize the tag ID as random numbers are mixed with its information.

The Internet of Things (IoT) approach tracks the vehicle with GPS, GSM, and RFID together. Prinsloo and Malekian [52] designed an antenna, modulation scheme, and software for vehicle tracking. The database server stored and transmitted the information with the Graphical User interface (GUI). The PHP scripting

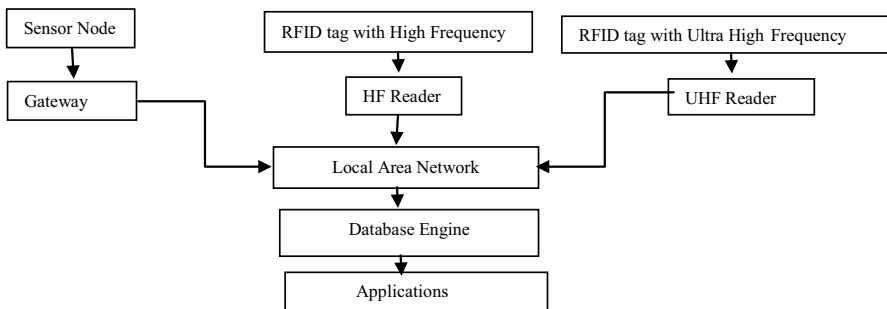


Fig. 3 Hybrid RFID-WSN systems

language created a database server and GUI with Microsoft.NET. A position estimation algorithm predicted the location. The GSM technology transmitted information to the cloud for storage and processing. The GUI helped display the information on a Google Maps interface.

4.6 RADAR & LIDAR

The Radio Detection and Ranging (RADAR) works on the principle of Doppler's effect as the moving body approaches nearer, frequency increases; and as it goes away, frequency decreases. The radar gun targets directly towards any vehicle and, the device displays the speed on it. Fang et al. [16] used a system that uses a K-band Gun transceiver as radio front and DSP chip as a signal processing unit. It was operated in the K-band and utilized digital signal processing. Hough Transform classifies and extracts spatial data. The accuracy was found to increase for detecting and classifying the vehicle. It has less cost as compared to the other traffic sensors. This device is efficient for researchers as well as traffic police. Continuous-wave radar detects and classifies the types of vehicles.

Luo et al. [36] used LiDAR point clouds that build up a 3D picture of the vehicle in Canada. The Kalman filter increased the accuracy with the Hungarian algorithm. MATLAB software was used to provide vehicle tracking solution. The results gave the average run time as 70 ms per frame, while vehicle travels at fix speed of 100 km/h.

4.7 Cameras

It provides more advantages as it gives pictorial data. Suresh et al. [63] found that video recording is useful for traffic analysis, as it determines the relationship between the speed volume and density. They fixed the cameras above highway lanes. The static cameras are used for recognizing the license plate from captured images. Ozbay and Ercelebi [48] detected the license plates of the vehicles using image processing algorithms.

Zhou et al. [78] worked on cameras which record the road traffic in different climatic conditions. They collected 2009 samples, in which 1218 samples belonged to vehicles, and the remaining photos had shadows, fog light, and solid commotion. The samples are divided into two sections; the preparation set which incorporates 263 vehicles and 246 non-vehicles that utilized in SVM-based classifiers, and the other set is used as the testing set to inspect the presentation of classifiers. For the estimation of the background, they proposed an improved algorithm by isolating the pictures into numerous little non-covered areas. The vehicle part can be found from the fields if there is some power change between the present picture and the foundation. All classified results are merged into a parallelogram that gives the state of information of every vehicle.

Schoepflin and Dailey [57] used the algorithm in three phases to adjust roadside traffic cameras that were introduced along the street side to track the vehicles with a traffic speed sensor. The algorithm determines the camera position for the roadway

utilizing the movement and edges of the vehicles. The calibrated cameras with camera position algorithms define the lane boundaries and endpoints of the road. The image coordinates transform into real-world coordinates; and distance divided by the inter-frame time determines the speed.

Zhang et al. [76] experimented using a video camera vehicle detection and classification framework for gathering traffic information using computer vision algorithms. Detection of shadows and removing it from successive images of the videos were carried out extracting the background images. They derived background images from a video sequence, detected the presence of a vehicle, and calculated pixel-based vehicle lengths for classification. Pixel length classifies the types of vehicles in real-time images as well as video processes through a plug and play system. The system was tested at three different locations under various traffic and environmental conditions. The accuracy for vehicle detection obtained was above 97%, and the total truck count error was lower than 9% for all three tests.

4.8 Satellite and Aerial Images

Remote sensing systems provide useful images for desired urban/suburban infrastructure, e.g., Landsat MSS and TM, IKONOS, World-View, Radarsat, etc. [23]. Razakarivony and Jurie [54] used machine learning techniques and implemented a protocol to generate and check the results. Aerial vehicles captured images for recognizing the road vehicles. The database of vehicles consisted of various classes, such as camping car, car, pick-up, tractor, truck, van, and other vehicles.

Cao et al. [9] used satellite images to implement transfer learning for recognizing the vehicles on the highway. They found that with the low pass filter, accuracy increases in aerial and satellite images. Vector maps and satellite image coordinates through ArcGIS and MapInfo software were utilized.

Zhang et al. [74] used the Conventional Neural Network (CNN) and Multilayer Perceptron (MLP) to test aerial photography and satellite sensor dataset in urban as well as rural areas of Southampton, UK. The sample data was gathered and divided for training and testing purposes. The CNN-MLP combined algorithm gave a better performance as compared to individual methods.

Geospatial information provided by optical remote sensing can be used for recognizing an object. Zhang et al. [77] used two datasets in optical remote sensing images to evaluate the performance of their proposed model. Intensity gradients represented the appearance with a rotation-invariant feature, and the support vector machine detects the geospatial objects.

Traffic estimation was done by Reinartz et al. [55] based on single-car measurements with the time series images achieved from the airborne sensor. Geocoding gave the speed and traffic-related parameters from the image sequences. The photos taken from different heights and angles provided information about traffic analysis, while the traditional and this method compared the image for reconstruction.

The UAVs are ubiquitous as these are cheaper and have vast applications. Instead of using single UAV, Elloumi et al. [15] used multiple UAVs for detecting the road traffic. The UAV camera provided real-time images and videos data from various

positions. The control station monitored the traffic information with an algorithm that generated the trajectory of UAV moving data point location.

The camera in the air monitors the remote areas which have less accessibility. It can capture several vehicles. It considers two scenarios; one standstill and the other dynamic. For both cases, there are different approaches for realizing the existence of vehicles, a pixel-level video foreground detector during standstill scenarios. In dynamic case, the images are registered initially, and then the pictures detect the moving vehicle. For changing the resolution, the training samples get updated. Xiang et al. [71] utilized the multi-threading method for the analysis of traffic data.

4.9 Geographic Information System

The GIS gathers, manages, and analyzes the data. The integrated information is in the form of maps and 3D representation. It analysis the position spatial information, and arranges the data in graphical format. Derekenaris et al. [14] merged the data from GIS, GPS, and GSM technologies in Greece for routing the path of ambulances. In an unlikely accident, the ambulance reaches the incident place using the shortest path. The navigation system provided the nearest hospital; and the smallest distance from the available routes. Maps showed the path with the data structures.

Aloquili et al. [5] determined the petrol/diesel level, vehicle speed, latitude, and longitude using GPS, GIS, GPRS and tracking software. They considered the factors, like traffic congestion, and topography of the region. Algorithm developed was assigned to choose the shortest way between the starting point and the end station. Security was given through Geofencing methods, while Dijkstra's and Kruskal's algorithms were applied to compute weights depending on the proposed cost function. The GIS represented the real-time position of the vehicles which was useful for road condition analysis.

4.10 Inductive Loops

The inductive loops are actually under the road surface of city roads or highways. The inductance of the coil is going to vary whenever any (metallic) vehicle passes through it. Marszalek et al. (2018) used inductive loop approach to recognize every passing car nearby. The instrument measured the impedance of the circuit. It contained the resistive and inductive magnetic part for identifying vehicle axles passing through it. A total of 4000 vehicles were captured from the video footage with usual road conditions, and the axle was detected with greater accuracy. The results achieved were approximately 71.8% accurate with a lifted axle, and 98.8% for other vehicles.

4.11 Smart Phones/Wireless Devices

Mobile phones with android operating system recognize the existence and types of vehicles. The radio signal power is checked frequently for road vehicle congestion, and traffic data can further reduce the emissions from fuel, duration of the journey.

Lewandowski et al. [33] used the random forest technique for checking and getting more approximation. They realized three types of vehicles; semi-trucks, trucks, and personal cars.

Li et al. [34] used bluetooth, Wi-Fi, mobile beacons together to give traffic information and differentiate between types of vehicles along the road at Wisconsin. The data server obtained all the information related to smartphones, and the distributed sensor network followed a single object. It coordinated between routing protocols and Constraint Satisfaction Problems (CSP) algorithms. The networking algorithms developed were geographic centric. In space–time cells, the cells get divided into less area and permitted the message through the entire network. Nodes managed the signal processing and communication in the whole area. Each activated node runs an energy detection algorithm whose output sample at an *a priori* constant rate estimates objects; it executes the method of recognizing energy.

Mohan et al. [40] used sensors, like accelerometer, microphone, GSM radio, and GPS in smartphones in Bangalore to check the road traffic conditions. They detected honks, braking, potholes, and bumps, and the Nericell sensors monitored the path of vehicles and road conditions. The system collected the data together from the smartphone and the server.

Alexander et al. [3] proposed a system for sensors to get that battery recharged through solar for observing the change in the state of vehicles. In remote locations, there is an interruption of electricity or no power. In that scenario, Zigbee nodes created the network. Every node consisted of an IR sensor that realizes some movement. In the star arrangement, one node acts as manager and others as slaves in the network. The sensor is attached to a power unit that can give energy continuously from the sun.

In tunnels or dense areas, GPS does not work efficiently, so along with roadside units (RSU) in vehicle inertial navigation system (INS) was proposed by Zarza et al. [73]. The locus circle increased accuracy. The unit along the path gave mobile signals, with the data obtained from the navigation system. After linearization, the least square method estimated the vehicle position for the given range and varying speed and INS estimation errors. It obtained the required locus circles. Lots of simulations were carried out to check the error rate.

4.12 Sensors Fusion

Kim et al. [29] used two different sensors which were placed together to realize the object by having perception from 3D and light amplification. For robust tracking of the objects, the period renewal method synchronizes the oldness of the object determined. Initially, the sensor processes the data for accurate tracking of the obstacles. Data processing algorithms were designed for, such as re-ordering of object data, object age, and time delay update. A period renewal method was developed to predict the progression time of the laser scanner. Kalman filter calibrated the information from light amplification and compared for identical results from a 3D device for a period of 1 ms and 66 ms, respectively. Statistical methods were used to check the results of the sensor's data.

LiDAR, camera and RADAR can gather the information together for the dynamic movement of an entity and checking for its directions. Chavez-Garcia and Aycard [10] collected the data in different driving scenarios and classified, like pedestrian, bike, car, and truck. A clustering method identified the dynamic things off the recognized area, and their procedure provided data on the observable shape and the closeness of the moving vehicle. The classifier was found to have a significant influence on the feature and speed as it checks the car position frequently.

5 Comparative Study of Sensors in Road Traffic

During the literature review, it was observed that various sensors, approaches, techniques, and input data are used by authors for several applications, including vehicle surveillance, traffic count, traffic classification, traffic management, etc. The selection of sensors is as per the feasibility of applications and areas. Therefore, a comparative study has been made to provide an insight to the readers and give some idea about the suitability of sensors and approaches for a specific application. It is given in Table 1.

Each sensor has its own way of working as well as its cost varies. Table 2 summarizes the pros and cons of the traffic sensors. The results obtained from various approaches proposed by different authors can provide the vital information for selecting the devices and technology. Table 3 presents a brief comparison of the equipment used along with the methodology, results, and end applications.

The sensors/technologies provide their strength and weakness in the road transportation applications. The inductive loop offers the best accuracy for vehicle count [8], and the high-frequency excitation model provides better vehicle classification. The major weakness of this sensor is lane closure required for maintenance and installation of the inductive loop each time as the pavement cut is essential. Ultrasonic sensors are cost-effective as they are used frequently for recognizing vehicle. Detection of vehicles is done either from the upper to lower part or from sideways inclined manner [24]. Lane violation detection, over height vehicle detection, distance estimation is possible with the ultrasonic sensors. Environment conditions have less impact on ultrasonic sensors [35]. The magnetic sensors are less susceptible to stresses of traffic. They can't sense any stopped vehicles without any interfacing of the sensors and the software [68]. Microwave Radar provides the most significant advantage by measuring the vehicle speed and direction [2]; the disadvantage it offers is that it cannot detect stopped vehicles on the road. The passive infrared sensor measures the speed while it is quite sensitive to bad weather [47]. Video cameras detect various lanes, and many vehicles, the only thing is the accuracy depends on the view and location of the camera. Lousy weather conditions affect the quality of images/videos. The maintenance/calibration of the camera is required periodically [57]. Smartphones offer more advantages as multiple sensors integrate with the android based operating system [40]. It can provide additional traffic and environmental related information to the user as well as the control station. The disadvantage is, there can be interference in the ISM frequency bands of operation.

Table 1 Working principle and applications of sensors technologies for road traffic

| Sensors/technology | Working principle | Application |
|------------------------------|--|--|
| Accelerometers | Vehicle wheel creates vibrations | Vehicle classification |
| Ultrasonic sensors | Echoes back signal after detection | Vehicle detection |
| Magnetic sensors | Change in the magnetic field | Vehicle detection, classification |
| RFID | Detection by Reader with Radio signal | Vehicle detection |
| Infrared Sensors | Emission of IR | Vehicle detection, speed estimation |
| LIDAR | Light reflects back | Vehicle detection and tracking |
| RADAR Gun | EM wave reflects back | Speed estimation |
| Inductive Loops | Vehicle induces eddy currents | Traffic detection |
| Video Cameras | video recording | Vehicle detection, traffic detection |
| Satellite/aerial images | Images captured through satellite or any aircraft. | Traffic detection |
| GIS | It captures, analyzes, and represents the data. | The vehicle tracking system, Navigation system |
| Wireless Device/smart Phones | Sending of the beacon signal. | Vehicle classification |

Table 2 Advantages and disadvantages of sensors/devices

| Sensors Technologies | Advantages | Disadvantages |
|-------------------------|---|--|
| Accelerometers | Vehicle axles are detected Robust in any weather conditions | Sensitive to any vibrations in the environment |
| Ultrasonic sensors | Multiple lanes are detected | Sensors are on one side and objects are on another side |
| Magnetic sensors | Robust in any weather conditions | To be installed very nearer the lane |
| RFID | Low power, low cost | If the card is out of range, cannot read the tag |
| Infrared Sensors | Along with vehicles, bicycle, as well as pedestrians, are detected | very much sensitive to light and weather conditions |
| LIDAR/RADAR | Can work in any condition | Installation is difficult and costly |
| Inductive Loops | It is flexible in design It provides all traffic-related parameters | For installation and maintenance, cutting of road pavement |
| Video Cameras | Exact details of vehicles are detected and are stored | Requires more memory for processing |
| Satellite/Aerial Images | It covers a larger geographical area It has a high spatial resolution | There can be distortion in images Image quality affects adversely under adverse weather conditions. |
| GIS | It offers a quick collection of data It gives better prediction and analysis | Systems and tools are quite complex |

Table 3 Comparison of the sensors and methodology

| References | Sensors/Source | Hardware, Software, and algorithm | Methodology | Results | Application |
|-------------------|--------------------|---|---|--|--|
| Ma et al. [37] | Accelerometer | Accelerometer and Magnetometer, weight in motion system, Moving average filter | The tire of the vehicle creates a vibration on the road pavement. | Axle spacing, vehicle count | The vehicle classification system, vehicle detection |
| Rivas et al. [56] | | Piezoelectric acceleration sensor, Data Acquisition module, Arduino Uno Microcontroller Vehicle detection algorithms | The algorithm Checks the vibrations level is higher than ± 0.5 mg in the data of each sensor. | Time vs. acceleration, vehicle detection, displacement, Travel direction | Vehicle detection, speed estimation, and vehicle classification. |
| Odat et al. [47] | Ultrasonic sensors | ARM Cortex microcontroller, six PIR thermopiles, Dynamic Bayesian Networks, Gaussian Mixture Models | Cross-correlation and wavelet transform estimate time delay | Temperature, error in | Speed Estimation, Observe Road vehicles scenarios and urban flash floods |
| Jo et al. [27] | | WSN, PLC microcontroller, Control module, voltage regulator, Routing protocol, vehicle detection algorithm | Sensors measure the distance, and algorithm converts distance data to traffic data | Distance, Average utilization of energy based on packet transmission periods, vehicle detection count, an Error rate | Traffic information |

Table 3 (continued)

| References | Sensors/Source | Hardware, Software, and algorithm | Methodology | Results | Application |
|-------------------------------|-----------------|--|---|---|---|
| Zhu and Yu [79] | Magnetic Sensor | Magnetic sensor, State machine detection and cross-correlation, parking recognition algorithm, vehicle speed detection algorithm | Determines the normalized cross-correlation between two signatures, Avelometer tests for accuracy. | Vehicle arrival, departure, determining speed accuracy. | Recognizing Vehicle, speed approximation |
| Sifuentes et al. [61] | | A magnetic sensor, optical sensor, wireless sensor node, Vehicle detection algorithm | LDR Sensor wakes upon arrival or departure, and Magnetic Sensor detects a change in Earth's magnetic field on the arrival of the vehicle. | Power consumption, magnetic signature | Vehicle detection |
| Taghvaeeyan and Rajamani [64] | | A magnetic sensor, XBeec wireless module, Magnetic field model | The distance between the two sensors is 0.9 m that determines the speed with cross-correlation. | Speed measurements of GPS, speed estimation error, Magnetic signature | Vehicle Counting, Classification, and Speed Measurement |

Table 3 (continued)

| References | Sensors/Source | Hardware, Software, and algorithm | Methodology | Results | Application |
|----------------------------|----------------|--|---|---|---|
| Ning et al. [46] | RFID | Modules of power, clock, LED, RFID, GPS, GSM sensing and core controlling, Microsoft Visual Studio 2008, Microsoft SQL Server 2005 LAND-MARC Algorithm | Microcontroller on the arrival of the vehicle, reads RFID tag data through the reader. The algorithm predicts navigation. | Vehicle position | Track vehicle Location |
| Xiong et al. [72] | | RFID readers, Wireless Sensor nodes, ContikiOS, Kalman filter | Montecarlo simulations give tracking performance as root mean square of error position. | RSSI, CDF, Positioning errors | Indoor Tracking |
| Prinsloo and Malekian [52] | | RFID Reader Module, GPS and GSM module, Database system with PHP, GIS | Design of RF Circular antenna with LC tank circuit, Kalman filter gives the prediction | Antenna Inductance, regulated supply, and interrogator distance | Vehicle location system |
| Pendur and Tasgaonkar [49] | | RFID, Cloud, Internet of things, Ethernet module | The vehicle has passive RFID tags; RFID reads the information of speed and timestamp and sends it to the cloud through the Ethernet module. | Graph of Distance Vs. Time and approximate velocity | Real-time velocity monitoring of a vehicle. |

Table 3 (continued)

| References | Sensors/Source | Hardware, Software, and algorithm | Methodology | Results | Application |
|----------------------|----------------|--|---|--|----------------------------------|
| Wen [69] | RFID | RFID, Infrared sensors JSP, JAVA, MySQL | The flooding algorithm determines the speed and the traffic on the road. The server gets the information and forwards it to all the centers in the city | Data of owner, vehicle, Toll fees, vehicle speed | Traffic management |
| Ji and Sprou [25] | GIS | Cell phones, PDA, Laptops, Accelerometers, GPS receivers, compass, Log distance path-loss model, GIS | Measurement module record the moving mobile's characteristics. Wi-Fi and GSM networks provide Localization | Location estimation, location error, direction, speed | Dynamic location computation |
| Aloquili et al. [5] | | GPS/GPRS modem, Dijkstra's and Kruskal's algorithms, Geofencing, VB 6, Microsoft Access database, | To provide an optimal path between source and destination from real-time information like travel time, traffic lights, JAM factor, and topography | Driver details, Tracking path of vehicles, Device ID, Distance | vehicle location tracking system |
| Soni [62] | | M680 Vehicle Counter, Inductive loops Twitter, HTML, CSS, JAVA script, PHP, MongoDB, | GIS integrates the traffic data from inductive loops and the tweets from the social media platform | Vehicle Count, Vehicle Classification, | Real-Time Road Traffic Analysis |
| Pritee and Garg [53] | | Dijkstra's algorithms, PostgreSQL, PostGIS, QGIS | Dijkstra's algorithms select the network and build the graph | Finding the Shortest path | analyzing road conditions |

Table 3 (continued)

| References | Sensors/Source | Hardware, Software, and algorithm | Methodology | Results | Application |
|----------------------|----------------|---|---|--|--------------------------------|
| Reinartz et al. [55] | Remote sensing | Airborne cameras, NAVTEQ database, vehicle detection algorithms | Sobel operator detects the edges of road images, that determines vehicle arrival or departure | Detections of cars, traffic congestion | Traffic monitoring |
| Mao et al. [38] | WSN | Light sensor, 40 sensor nodes, and Base station, Probability-based | Light analyses the moving patterns i.e. height and speed of 5 persons, sensor informs change in environment to sink node | Distance estimation based on changes in RSSI and Link Quality Indicator(LQI) | Indoor passive tracking |
| Wenjie et al. [70] | | Vehicle unit, roadside unit, intersection unit, Minimum travel time optimization algorithm | To configure the transport network, optimization of traffic parameters like length, lane numbers, and speed | Mean speed of Traffic network | Traffic control system |
| Tan et al. [65] | | Mobile sensors, static sensors, Greedy scheduling algorithm, Movement scheduling algorithm, | 75 sensor nodes detect Defense vehicles at the intersection. To get simulation results, Training of data set in the algorithm, that takes real data traces for target detection | Receiver operating characteristics, Detection probability | Target detection |
| Sharp et al. [60] | | Berkeley Mica2Dot nodes, 100 sensor nodes, Magnetometer, autonomous robot, an ultrasound transceiver TinyOS, flooding algorithm, the landmark routing algorithm | Nodes near evader senses and calibrates events. Selection of Leader and aggregation of data, Robot chases the evader after interception planning | Route time, Evader GPS position, Intruder tracking | Vehicle detection and tracking |

Table 3 (continued)

| References | Sensors/Source | Hardware, Software, and algorithm | Methodology | Results | Application |
|----------------------------|-------------------------------|---|---|---|---|
| Khakpour et al. [28] | Vehicular Adhoc Network VANET | Clustering, flooding, TinyOS simulator, Ns2 | Clustering reduces data propagation and facilitates network management | Cluster head lifetime, | Target tracking |
| Kumar et al. [30] | Video Cameras | Data Set from Video cameras | Artificial Neural Network predicts traffic flow using the record of traffic volume, speed, density, and time | Traffic volume | Traffic flow prediction |
| Sharma et al. [59] | Video Cameras | Morphological Images | Differential morphology closing profile extracts vehicle information with image processing | Vehicle Detection accuracy | Vehicle detection |
| References | Sensors/Source | Hardware, Software and algorithm | Methodology | Results | Application |
| Kumar and Kushwaha [31] | Video Cameras | Video Camera, Open CV, JAVA, MySQL | Comparison of vehicle position in the successive frames | Detection Accuracy in Morning, Afternoon, evening, cloudy day | Vehicle detection and Speed Estimation |
| Anandhalli and Baligar [6] | Video Cameras | Raspberry Pi, Open CV, C++, Kalman Filter, | The algorithm detects the number of vehicles on the road. HSV color domain differentiates the vehicles, Kalman filter tracks it | Accuracy of Front View, Side View, Rearview, Top view, Multi-View | Vehicle recognizing at run time and Tracing |

Table 3 (continued)

| References | Sensors/Source | Hardware, Software and algorithm | Methodology | Results | Application |
|----------------------------|----------------|--|---|---|-------------------------------|
| Hostettler and Djuric [22] | Sensor Fusion | Accelerometer, Magnetometer Particle filtering, Kalman filter, 100 Monte Carlo simulations | Sampling Importance particle filter processes with Rao-Blackwellization method the data of accelerometer and magnetometers | Position, speed, mean estimation error | Vehicle tracking |
| Kim et al. [29] | | Laser Scanner, stereo vision Kalman filter | The algorithm determines the time delay of the sensor. Kalman Filter predicts the data of the Laser scanner and matches with stereo vision data | Object matching | Vehicle detection |
| Planas et al. [50] | | Temperature, Pressure, Vehicle inclination, On-Board Terminals, User Monitoring Terminals software, Decision support software modules, risk knowledge platform | GPS gives vehicle positions to OBT. Information is sent to the server, Occurrence of events, school transportation is retrieved from external sources, UMT software displays Geo-referenced information | Vehicle ID, Address and GPS coordinates | Monitoring of dangerous goods |

Sensors technologies provide a different aspect of collecting vehicle traffic data. Accelerometers recognized larger size of vehicles approximately as compared to the smaller size of vehicles [7]. Ultrasonic sensor system identified the improper traffic rule violation of the vehicles. Liu et al. [35] achieved an accuracy of more than 90%. Magnetic sensors provided good accuracy for vehicle entry and exit. These sensors describe the types of vehicles based on the magnetic signature. The accuracy rate is more than approximately 99% was achieved for a vehicle at a standstill [79]. RFID, if used with other technologies, like GPS, WSN, and INS. These sensors provide more benefits considering the application is indoor area or tunnels [45]. Unmodulated continuous wave radar is cost-effective as compared to other kinds of sensing devices [16]. The LiDAR provides a more magnificent view and 3D perception of the objects with a 360° scanning feature. Data processing is also less cumbersome. It works in any complex environment when multiple vehicles are to be detected [36]. The detector with the inductive loop determines the vehicle length (Marszalek et al. 2018).

The best way to recognize the vehicles that have storage facility is with the cam-corders that can capture pictures as well as take videos throughout the day. The detection is best if it is located at the best view angle to cover a larger area of road lanes. During the unlikely climate scenarios, working is going to get deteriorated [78]. Algorithms can detect vehicles without training data in the satellite images [9]. Multi-temporal data sets are readily available to the researchers frequently with satellite images. Computer vision approaches require machine learning and training of data for analysing remote sensing images [54]. In GIS environment, georeferencing provides secure tracking of the vehicles carrying the goods and commuters on the road. It determines the shortest route which is very useful in traffic management [5].

6 Conclusion

In this study, we have summarized the literature review on vehicle detection, tracking, and traffic estimation with sensors and technologies. We have provided a survey of vehicle detection techniques so that readers can have a fair idea of selecting the sensor for road traffic monitoring and management. Smart sensors installed at the intersections of the road would help avoid traffic congestion. Emergency vehicles may be given the highest priority, and their waiting time is minimized. Along with WSN research studies on traffic control and management, RFID, Zigbee, Vehicular Ad hoc Networks (VANET), bluetooth devices, cameras, and infrared signals have been used [43]. Three basic things are always considered sensing, traffic control, and safety. Sensors gather the traffic data and provide it to the control station. The traffic control station manages the traffic congestion, while the security is active during the traffic jams and road rules violation.

Modern technologies offer electronic toll control at toll plazas. Fast tags vehicles have a separate lane and waiting time decreases. Service roads are for local traffic as it separates from transport. Two-lane highways are to be converted to 4-lanes, while 4-lanes are widening to 6 lanes. Proper grade separator, median openings, footpath for pedestrians are also required. Separate roads as per the speed, like slow-moving,

medium moving, and fast-moving vehicles are needed to avoid obstructions and accidents [18].

Railway level crossings on NH network should not interfere with highways; over-bridge or under-bridge constructed gives a safer and faster journey. Ring road and link roads make the intercity travel better as proper connectivity is available in the city [18]. Bypass roads can separate the NH from entering the central city and reduce traffic congestion. However, road widening, development of the road infrastructure depends upon the environment, and land acquisitions, and financial budget aspects.

Vehicle detection, classification, and tracking utilize the state of art technologies. The location-based services provide the vehicle count, speed, volume, density to the driver as well as the monitoring station. Various mathematical models estimate the road traffic. Sensors/technologies offer a higher demand in the ITS. It covers a vast number of applications that can minimize the traffic congestion issues with the integrated data from sensor fusion. The smart cities will have the transportation sector connected to the IoT.

References

1. Akyildiz, I., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). Wireless sensor networks: A survey. *ELSEVIER Journal on Computer Networks*, 38(4), 393–422.
2. Alessandretti, G., Broggi, A., & Cerri, P. (2007). Vehicle and guard rail detection using radar and vision data fusion. *IEEE Transactions on Intelligent Transportation Systems*, 8(1), 95–105.
3. Alexander, A., Taylor, R., Vairavanathan, V., Fu, Y., Hossain, E., & Noghianian, S. (2008). Solar-powered ZigBee-based wireless motion surveillance: A prototype development and experimental results. *Journal of Wireless Communications and Mobile Computing*, 8, 1255–1276.
4. Almomani I., Alkhalil N., Ahmad E. & Jodeh R. (2011). Ubiquitous GPS vehicle tracking and management system. In *IEEE conference on applied electrical engineering and computing technologies*, 6–8 Dec. 2011, Amman, Jordan
5. Aloquili, O., Elbanna, A., & Al-Azizi, A. (2009). Automatic vehicle location tracking system based on GIS environment. *The IET Software*, 3(4), 255–263.
6. Anandhalli, A., & Baligar, V. (2018). A novel approach in real-time vehicle detection and tracking using Raspberry Pi. *ELSEVIER Alexandria Engineering Journal*, 57, 1597–1607.
7. Bernas, M., Placzek, B., Korski, W., Loska, P., Smyła, J., & Szymała, P. (2018). A survey and comparison of low-cost sensing technologies for road traffic monitoring. *Sensors Journal*, 18(10), 3243. <https://doi.org/10.3390/s18103243>.
8. Burnos, P., Gajda, J., Piwowar, P., Sroka, R., Stencel, M., & Zeglen, T. (2007). Measurements of road traffic parameters using inductive loops and piezoelectric sensors. *Metrology and Measurement Systems Journal*, 14(2), 187–203.
9. Cao, L., Wang, C., & Li, J. (2016). Vehicle detection from highway satellite images via transfer learning. *ELSEVIER Journal on Information Sciences*, 366, 177–187.
10. Chavez-Garcia, R., & Aycard, O. (2016). Multiple sensor fusion and classification for moving object detection and tracking. *IEEE Transactions on Intelligent Transportation Systems*, 17(2), 525–534.
11. Chen W., Chen L., Chen Z., & Tu, S. (2006). WITS: A wireless sensor network for intelligent transportation system. In: *Proceedings of the first international multi-symposiums on computer and computational sciences*, 20–24 June 2006, Hanzhou, Zhejiang, China.
12. Chen Y., Cheng L., Chen C. & Ma, J. (2009). ‘Wireless sensor network for data sensing in intelligent transportation system. In: *VTC spring 2009: IEEE 69th vehicular technology conference*, 26–29 April 2009, Barcelona, Spain.
13. Cheng, G., & Han, J. (2016). A survey on object detection in optical remote sensing images. *ISPRS Journal of Photogrammetry and Remote Sensing*, 117, 11–28.

14. Derekenaris, G., Garofalakis, J., Makris, C., Prentzas, J., Sioutas, S., & Tsakalidis, A. (2001). Integrating GIS, GPS and GSM technologies for the effective management of ambulances. *Journal of Computers, Environment, and Urban Systems*, 25(3), 267–278.
15. Elloumi, M., Dhaou, R., Escrig, B., Idoudi, H. & Saidane, L. (2018). Monitoring road traffic with a UAV-based system. In: *IEEE wireless communications and networking conference (WCNC 2018)* (pp. 1–6) 15–18 April 2018, Barcelona, Spain.
16. Fang J., Meng H., Zhang H., & Wang, X. (2007). A low-cost vehicle detection and classification system based on unmodulated continuous-wave radar. In *Proceedings of the 2007 IEEE intelligent transportation systems conference Seattle*, 30 Sept.-3 Oct. 2007, Seattle, WA, USA.
17. Fernández-Ares, A., Mora, A., Odeh, S., García-Sánchez, P., & Arenas, M. (2017). Wireless monitoring and tracking system for vehicles: A study case in an urban scenario. *ELSEVIER Journal of Simulation Modelling Practice and Theory*, 73, 22–42.
18. Government of India, Ministry of Road Transport & Highways, 12th five year plan. (2012–17). *Report of the Working Group on Central Roads Sector*.
19. Guerrero-Ibáñez, J., Zeadally, S., & Contreras-Castillo, J. (2018). Sensor technologies for intelligent transportation systems. *Sensors Journal*, 18(4), 1212. <https://doi.org/10.3390/s18041212>.
20. Hanan, M., Mustapha, A., Hussain, A. & Basri, H. (2012). Intelligent bus monitoring and management system. In *Proceedings of the world congress on engineering and computer science*, 24–26 October 2012, San Francisco, USA.
21. Hatem, B., & Habib, H. (2009). Bus management system using RFID in WSN. In *European and mediterranean conference on information systems*, April 12–3 2009, Abu Dhabi, UAE.
22. Hostettler, R., & Djuric, P. (2015). Vehicle tracking based on fusion of magnetometer and accelerometer sensor measurements with particle filtering. *IEEE Transactions on Vehicular Technology*, 64(11), 4917–4928.
23. Jensen, J., & Cowen, D. (1999). Remote sensing of urban/suburban infrastructure and socio-economic attributes. *Journal of Photogrammetric Engineering and Remote Sensing*, 65(5), 611–622.
24. Jeon, S., Kwon, E., & Jung, I. (2014). Traffic measurement on multiple drive lanes with wireless ultrasonic sensors. *Sensors Journal*, 14(12), 22891–22906. <https://doi.org/10.3390/s141222891>.
25. Ji, Y., & Sprou, G. (2009). FreeMobility: Dynamic location computing using GIS. *Wiley Journal on Wireless Communications and Mobile Computing*, 13, 998–1013.
26. Jo, Y., & Jung, I. (2014). Analysis of vehicle detection with WSN-based ultrasonic sensor. *Sensors Journal*, 14(8), 14050–14069.
27. Jo, Y., Choi, J., & Jung, I. (2014). Traffic information acquisition system with ultrasonic sensors in wireless sensor networks. *Hindawi Publishing Corporation International Journal of Distributed Sensor Networks*, 2014, 9610.
28. Khakpour, S., Pazzi, R., & Khatib, K. (2017). Using clustering for target tracking in vehicular ad hoc networks. *ELSEVIER Journal of Vehicular Communications*, 9, 83–96.
29. Kim, S., Kim, H., Yoo, W., & Huh, K. (2016). Sensor fusion algorithm design in detecting vehicles using laser scanner and stereo vision. *IEEE Transactions on Intelligent Transportation Systems*, 17(4), 1072–1084.
30. Kumar, K., Parida, M., & Katiyar, V. (2013). ‘Short term traffic flow prediction for a non-urban highway using artificial neural network’, 2nd Conference of Transportation Research Group of India. *Procedia - Social and Behavioural Sciences, Agra, India*, 104, 755–764.
31. Kumar, T., & Kushwaha, D. (2016). An efficient approach for detection and speed estimation of moving vehicles. In *Twelfth international multi-conference on information processing-2016 (IMCIP-2016), procedia computer science*, vol. 89, pp. 726–731.
32. Lee, W., Tseng, S., & Shieh, W. (2010). Collaborative real-time traffic information generation and sharing framework for the intelligent transportation system. *ELSEVIER Journal of Information Sciences*, 180(2010), 62–70.
33. Lewandowski, M., Placzek, B., Bernas, M., & Szymala, P. (2018). Road traffic monitoring system based on mobile devices and BLUETOOTH low energy beacons. *Wiley Hindawi Journal of Wireless Communications and Mobile Computing*. <https://doi.org/10.1155/2018/3251598>.
34. Li, D., Wong, K., Hu, Y., & Sayeed, A. (2002). Detection, classification, and tracking of targets. *IEEE Signal Processing Magazine*, 19(2), 17–29.
35. Liu, J., Han, J., Lv, H., & Li, B. (2015). An ultrasonic sensor system based on a two-dimensional state method for highway vehicle violation detection applications. *Sensors Journal*, 15, 9000–9021.
36. Luo, Z., Habibi, S., & Mohrenschildt, M. (2016). LiDAR based real-time multiple vehicle detection and tracking. *International Journal of Computer and Information Engineering*, 10(6), 1125–1132.

37. Ma, W., Xing, D., McKee, A., Bajwa, R., Flores, C., Fuller, B., et al. (2014). A wireless accelerometer-based automatic vehicle classification prototype system. *IEEE Transactions on Intelligent Transportation Systems*, 15(1), 104–111.
38. Mao, X., Tang, S., Wang, J., & Li, X. (2013). iLight: Device-free passive tracking using wireless sensor networks. *IEEE Sensors Journal*, 13(10), 3785–3792.
39. Mintsis, G., Basbas, S., Papaioannou, P., Taxiltaris, C., & Tziavos, I. (2004). Applications of GPS technology in the land transportation system. *ELSEVIER European Journal of Operational Research*, 152, 399–409.
40. Mohan, P., Padmanabhan, V., & Ramjee, R. (2008). Nericell: Rich monitoring of road and traffic conditions using mobile smartphones. In *SensSys 08*, November 5–7, 2008, Raleigh, North Carolina, USA.
41. Mustapha, H. M., Hussain, A., & Basri, H. (2009). 'UKM campus bus identification a monitoring using RFID and GIS. In *Proceedings of IEEE conference on research and development*, 16–18 Nov 2009, Serdang, Malaysia.
42. Nafar, F., & Shamsi, H. (2018). Design and implementation of an RFID-GSM based vehicle identification system on highways. *IEEE Sensors Journal*, 18(17), 7281–7293.
43. Nellore, K., & Hancke, G. (2016). A survey on urban traffic management system using wireless sensor networks. *Sensors Journal*. <https://doi.org/10.3390/s16020157>.
44. Nguyen, D., Dow, C., & Hwang, S. (2018). An efficient traffic congestion monitoring system on the internet of vehicles. *Hindawi Wireless Communications and Mobile Computing*, 2018, 9136813.
45. Ni, L., Zhang, D., & Souryal, M. (2011). RFID -based localization and tracking technologies. *Journal of IEEE Wireless Communications*, 18(2), 45–51.
46. Ning, Y., Zhong-qin, W., Malekian, R., Ru-chuan, W., & Abdullah, A. H. (2013). Design of accurate vehicle location system using RFID. *Elektronika Ir Elektrotehnika Journal*, 19, 8.
47. Odat, E., Shamma, J., & Claudel, C. (2018). Vehicle classification and speed estimation using combined passive infrared/ultrasonic sensors. *IEEE Transactions on Intelligent Transportation Systems*, 19(5), 1593–1606.
48. Ozbay, S., & Ercelebi, E. (2005). Automatic vehicle identification by plate recognition. *World Academy of Science, Engineering and Technology*, 1(9), 1418–1421.
49. Pendor, R., & Tasgaonkar, P. (2016). An IoT framework for intelligent vehicle monitoring system. In *International conference on communication and signal processing*, April 6–8, 2016, Melmaruvathur, India, pp. 1694–1696.
50. Planas, E., Pastor, E., Presutto, F., & Tixier, J. (2008). Results of the MITRA project: Monitoring and intervention for the transportation of dangerous goods. *ELSEVIER Journal of Hazardous Materials*, 152, 516–526.
51. Premebida, C., Ludwig, O., & Nunes, U. (2009). LIDAR and vision-based pedestrian detection system. *Wiley Journal of Field Robotics*, 26(9), 696–711.
52. Prinsloo, J., & Malekian, R. (2016). Accurate vehicle location system using RFID, and Internet of Things approach. *Sensors Journal*, 16(6), 825. <https://doi.org/10.3390/s16060825>.
53. Pritee, K., & Garg, R. (2017). 'Identification of optimum shortest path using multipath dijkstra's algorithm approach. *International Journal of Advanced Remote Sensing and GIS* 2017, 6(1), 2442–2448.
54. Razakarivony, S., & Jurie, F. (2016). Vehicle detection in aerial imagery: A small target detection benchmark. *ELSEVIER Journal of Visual Communication and Image Representation*, 34, 187–203.
55. Reinartz, P., Lachaise, M., Schmeer, E., Krauss, T., & Runge, H. (2006). Traffic monitoring with serial images from airborne cameras. *ISPRS Journal of Photogrammetry and Remote Sensing*, 61, 149–158.
56. Rivas, J., Wunderlich, R., & Heinen, S. (2017). Road vibrations as a source to detect the presence and speed of vehicles. *IEEE Sensors Journal*, 17(2), 377–385.
57. Schoepflin, T., & Dailey, D. (2003). Dynamic camera calibration of roadside traffic management cameras for vehicle speed estimation. *IEEE Transactions on Intelligent Transportation Systems*, 4(2), 90–98.
58. SeokJu, L., Girma, T., & Jaerock, K. (2014). Design and implementation of vehicle tracking system using GPS/GSM/GPRS technology and smartphone application. In *IEEE world forum on internet of things*, 6–8 March 2014, Seoul, Korea.
59. Sharma, B., Katiyar, V., Gupta, A., & Singh, A. (2014). The automated vehicle detection of highway traffic images by differential morphological profile. *Journal of Transportation Technologies*, 4, 150–156.

60. Sharp, C., Schaffert, S., Woo, A., Sastry, N., Karlof, C., Sastry, S., & Culler, D. (2005). Design and implementation of a sensor network system for vehicle tracking and autonomous interception. robotics.eecs.berkeley.edu.
61. Sifuentes, E., Casas, O., & Pallas-Areny, R. (2011). Wireless magnetic sensor node for vehicle detection with optical wake-up. *IEEE Sensors Journal*, *11*(8), 1669–1676.
62. Soni, U. (2019). Integration of traffic data from social media and physical sensors for near real-time road traffic analysis. *M.Sc Thesis, Faculty of Geo-Information Science and Earth Observation of the University of Twente, March 2019*.
63. Suresh, K., Mahesh, G., & Rajagopalan, A. (2007). Superresolution of license plates in real traffic video. *IEEE Transactions On Intelligent Transportation Systems*, *8*(2), 321–331.
64. Taghvaeeyan, S., & Rajamani, R. (2014). Portable roadside sensors for vehicle counting, classification, and speed measurement. *IEEE Transactions on Intelligent Transportation Systems*, *15*(1), 73–83.
65. Tan, R., Xing, G., Wang, J., & Cheung, H. (2008). Collaborative target detection in wireless sensor networks with reactive mobility. In *16th international workshop on quality of service*, 2–4 June 2008, Enschede, Netherlands.
66. Tubaishat, M., Zhuang, P., & Shang, Q. (2009). Wireless sensor networks in intelligent transportation systems. *Wiley Journal of Wireless Communications and Mobile Computing*, *9*, 287–302.
67. Vancin, S., & Erdem, E. (2017). Implementation of the vehicle recognition systems using wireless magnetic sensors. *Sadhana Journal*, *42*(6), 841–854.
68. Velisavljevic, V., Cano, E., Dyo, V., & Allen, B. (2016). Wireless magnetic sensor network for road traffic monitoring and vehicle classification. *Journal of Transport and Telecommunication*, *17*(4), 274–288.
69. Wen, W. (2010). An intelligent traffic management expert system with RFID technology. *ELSEVIER International Journal of Expert Systems with Applications*, *37*, 3024–3035.
70. Wenjie, C., Liqiang, G., Zhilei, C., Zhanglong, C., & Shiliang, T. (2005). An intelligent guiding and controlling system for transportation network based on wireless sensor network technology. In *Proceedings of fifth international conference on computer and information technology*, 21–23 Sept. 2005, Shanghai, China.
71. Xiang, X., Zhai, M., Lv, N., & Saddik, A. (2018). Vehicle counting based on vehicle detection and tracking from aerial videos. *Sensors Journal*, *18*(8), 5. <https://doi.org/10.3390/s18082560>.
72. Xiong, Z., Song, Z., Scalera, A., Ferrera, E., Sottile, F., Brizzi, P., et al. (2013). Hybrid WSN and RFID indoor positioning and tracking system. *EURASIP Journal on Embedded Systems*. <https://doi.org/10.1186/1687-3963-2013-6>.
73. Zarza, H., Yousefi, S., & Benslimane, A. (2016). RIALS: RSU/INS-aided localization system for GPS-challenged road segments. *Wiley Journal on Wireless Communications and Mobile Computing*, *2016*, 1290–1305.
74. Zhang, C., Pan, X., Li, H., Gardiner, A., Sargent, I., Hare, J., et al. (2018). A hybrid MLP-CNN classifier for very fine resolution remotely sensed image classification. *ISPRS Journal of Photogrammetry and Remote Sensing*, *140*, 133–144.
75. Zhang, E., Jiang, W., Kuang, Y., & Umer, M. (2011). Active RFID positioning of vehicles in road traffic. In *The 11th international symposium on communications & information technologies (ISCIIT 2011)*, October 12–14, 2011, Zhejiang University, Hangzhou, China.
76. Zhang, G., Avery, R., & Wang, Y. (2007). Video-based vehicle detection and classification system for real-time traffic data collection using uncalibrated video cameras. *Journal of the Transportation Research Board*, *1993*, 138–147.
77. Zhang, W., Sun, X., Wang, N., & Fu, K. (2015). A generic discriminative part-based model for geospatial object detection in optical remote sensing images. *ISPRS Journal of Photogrammetry and Remote Sensing*, *99*, 30–44.
78. Zhou, J., Gao, D., & Zhang, D. (2007). Moving vehicle detection for automatic traffic monitoring. *IEEE Transactions On Vehicular Technology*, *56*(1), 51–59.
79. Zhu, H., & Yu, F. (2016). A cross-correlation technique for vehicle detections in wireless magnetic sensor network. *IEEE Sensors Journal*, *16*(11), 4484–4494.