TRAFFIC MANAGEMENT

Innovation

This section first discusses the recent research developments in intelligent traffic management including system models for traffic updates, traffic congestion measures, emergency vehicle handling, and applications of roadside units to deliver messages. Current advances in cost-effective and power-efficient wireless sensor nodes for traffic monitoring follow this. This section also includes specific printed circuit boards based on sensor nodes to detect vehicles, estimate speed, and classify them. The discussion includes the features of these nodes, their pros, and cons.

2.1. Real-time traffic updates

Real-time traffic monitoring systems play a key role in the transition toward smart cities. A considerable amount of literature has been published on intelligent traffic management systems based on the IoT paradigm [25,56,60,61]; Z [38]. Autonomous traffic sensing is at the heart of smart city infrastructures, wherein smart wireless sensors are used to measure traffic flow, predict congestion, and adaptively control traffic routes. Doing so effectively provides an awareness that enables more efficient use of resources and infrastructure.

Identifying and measuring congestion is the very first step in the traffic management process [40]. The flow, occupancy, density is the widely used traffic congestion measures, which are mostly obtained from images or videos captured by vision systems initially [53]. Based on these measures, the traffic warning messages are broadcasted through smartphones, radio, televisions, light signals, dynamic variable message signs, or display units. Among them, the mobile-based web applications received much attention among researchers [18,56].

Most of the recent developments in delivering real-time traffic updates used the congestion estimates to dynamically control the traffic signal [3,27,32,43,59,63]. An IoT based real-time traffic monitoring system is proposed [43] for dynamic handling of traffic signals based on traffic density. The proposed system uses a set of ultrasonic sensors and has two modules: one for vehicle monitoring and other for priority management. The ultrasonic sensors are used to detect vehicles, and the density levels of a given road are sent to an LCD, and the data sent to the server for later usage. In similar research [63], the authors proposed an ultrasonic sensor-based system model specifically for road intersections. In addition to traffic signal lightings, the system alarms on any false vehicle activities such as crossing the red signals. In another research, an IoT based smart traffic management system is proposed [29] to manage real-time traffic through both central and local servers. The data collection layer uses sensors, cameras, and RFIDs. The application layer automatically controls the traffic signal based on traffic density and provides a daily report through a web application. Besides sensors, video monitoring is also used to estimate traffic congestion density [32] and update traffic signals in real-time.

The internet of connected vehicles is another research development in this area [26] to collect real-time traffic data. The connected vehicles support individual vehicle monitoring which enables efficient emergency vehicle management. Integrating roadside units (eg: traffic lights) with the vehicular network to ensure the trustworthiness of traffic events [66]. The emergency vehicle (e.g. Police cars, Fire engines, Ambulances) handling is very critical, the delay of every second matter because of the urgency of the services they are providing. Automatic scheduling of emergency vehicles can be performed by controlling the traffic signals [45,64] to improve the response time [57]. However, these systems are specifically designed for highways.

As this research does not anticipate any smart devices with the drivers, the traffic updates through roadside message units are analyzed in detail. A patented device for displaying traffic conditions [17] is designed to install on the roadside. The graphical message unit displays the upcoming traffic conditions and incidents through messages, signs, or colors. The studies on the impact of dynamic message signs through roadside message units show that it has received acceptance among drivers [23,35,65]. The dynamic message signs can be delivered in permanent mode through roadside message units (installed on bridges, toll plazas, tunnels, etc.) or portable units. The portable units are mainly used to warn about unusual traffic incidents. The roadside units mostly display the messages about over spilled roads, planned activities, environmental updates, traffic flow conditions, etc. The impact analysis of such message units reported that they mainly assist elderly drivers in their decision making [23].

The transportation project for the Beijing Olympics (F [69]. is a great example of providing traffic updates through public message units. The project used changeable message boards, radios, television, internet, and in-vehicle displays to monitor and dispatch traffic updates. However, system development was quite expensive due to advanced programs and devices [5]. After that, several research efforts have been made in this area to provide real-time traffic updates. A system is proposed to display traffic intensity through three different light colors on installed electronic boards at decision points [60]. In this system, the real-time traffic density is calculated from the average vehicle speed determined by vehicle detection systems. The authors apply image processing algorithms to process real-time traffic videos, and the traffic congestion estimation is based on optical flow. Similarly, electronic signboards are used to avoid congestions by setting up different speed limits [21].

The studies discussed above are tested for highways, and real-time updates are delivered through traffic signals or mobile applications. Instead, this research proposes a system model for real-time traffic updates through roadside message units using an IoT platform Nowadays, digital electronic boards are widely used in smart campuses, that can be also reused (if any) to deliver traffic updates during peak hours. Next, discuss the wireless sensors which are mainly used for vehicle detection, classification, speed estimation, etc.

2.2. Wireless sensors for vehicle data collection

This section presents the review of sensors that are used for vehicle detection and classification. The sensors used in intelligent traffic monitoring systems can be on-road sensors or in-vehicle sensors. The on-road traffic sensors can be again classified into two types: intrusive and non-intrusive. The intrusive sensors are paved on the road and are costly compared to non-intrusive sensors. The intrusive sensors provide accurate information; however, they are questioned for the expenses in terms of installation. maintenance, repair costs [22]. The maintenance of such sensors requires road lane closures and traffic disruptions. The non-intrusive sensors can be fixed on different parts of roads/roadsides. This includes magnetic sensors [16,31], ultrasonic sensors [39], infrared sensors [47], acoustic sensors [9,46], video cameras [12]; B [36]. Each sensor has its advantages and disadvantages. The ultrasonic sensors are prone to environmental factors [6]. The video monitoring systems are comparatively costly than other sensors when considering the purchase, installation, and maintenance costs [55]. However, the sensors are relatively less expensive in purchase costs. A comparison of different intrusive and non-intrusive sensors have been already reported in a few kinds of research [44,48,55]. The infrared sensors are sensitive to bad weather; acoustic sensors do not give accurate results during cold temperatures. The magnetic sensors are unable to detect the vehicles which are not moving [44]; however, there is no climatic influence. The magnetic sensors are widely used for vehicle detection and classification because of its easy installation, portability, and low cost [16,72]. The vehicle speed and length can be estimated by one or more magnetic sensors, which will help to approximate the road space occupancy measure.

Besides different types of sensors, a few research efforts have attempted to develop printed circuit boards (PCBs), which can be directly adapted for vehicle detection/speed estimation/classification such as PRS [62], LCTS [72], iVCCS [8], and CPIUS [47]. Fig. 1 shows the PCBs of PRS, LCTS, and iVCCS sensor nodes. The main objective of all these researches is to design and develop inexpensive and portable sensor nodes. On average, a single sensor node costs an average of $30 and operational for many years [6].

Fig. 1

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Fig. 1. (a) LCTS Sensor Node [72], (b) PRS Physical Board [47], and (c) iVCCS Physical Board [8].

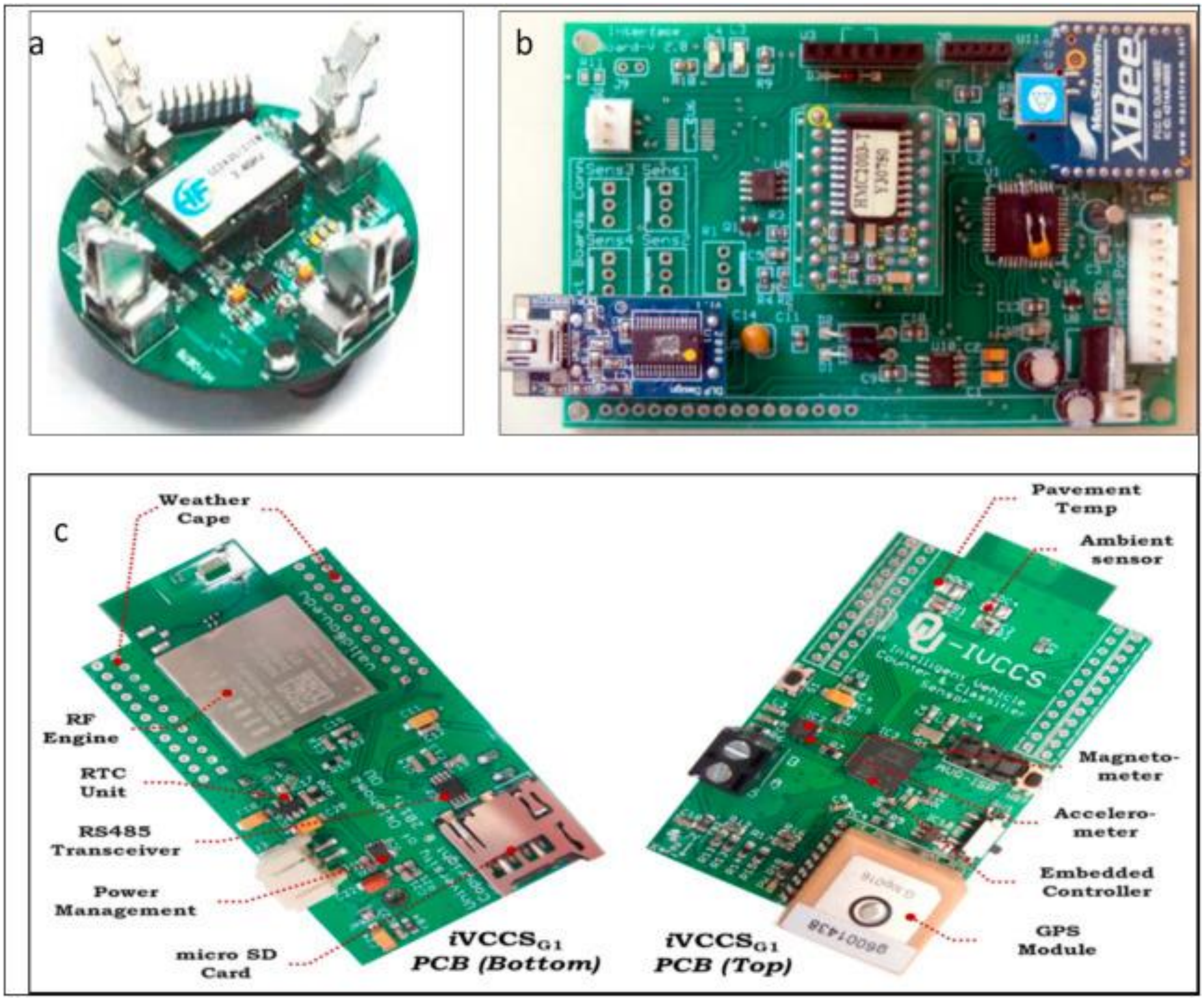
PRS is a portable roadside sensor for vehicle detection, counting, classification, and speed estimation [62]. PRS uses a magnetic sensor for vehicle detection. The single PCB board of PRS contains two magnetic sensors (HMC2003). This sensor uses the XBee module for wireless communication. PRS shows an accuracy of 99% in vehicle detection, and the maximum error rate of speed estimation is 2.5% (in a range of 5–27 m/s). Besides, the system also detects the right intersection. The vehicle length and height are estimated from the magnetic length.

LCTS is another low-speed congested traffic sensor node with a magnetic sensor specifically for a single lane road [72]. The sensor node is designed using magnetic sensor HMC5883L. In addition to the magnetic sensor, the node also contains a sound sensor and four infrared sensors. However, the magnetic sensor alone performs vehicle detection and classification. The validation results show a detection accuracy of 99.05% and a classification accuracy of 93.66%.

The iVCCS is an intelligent vehicle counting and classification sensor; the node has different sensors and components such as temperature sensor, accelerometer, magnetic sensor, GPS module, real-time clock unit, memory unit, etc. [8]. The iVCCS is a small battery-powered node with a 6-axis magnetic sensor and accelerometer FXOS8700. It uses a Zigbee wireless communication. The iVCCS nodes are validated in different field trials and exhibit a 99.98% accuracy in vehicle detection, 97% accuracy in vehicle classification, and 97.11% in speed estimation. The consistency of the sensor's output under different conditions is tested and showed high similarity. Besides, the sensor node is portable and can be installed on the road as well as on roadsides.

CPIUS is the combined passive infrared and ultrasonic sensors (CPIUS) for vehicle classification and speed estimation [47]. The measurements from passive infrared sensors and ultrasonic sensors are used for vehicle classification. They produce a high accuracy in vehicle detection (99%), the mean absolute error in speed estimation is approximately 5.87 km/h, and a mean absolute error of 0.73 m in vehicle length estimation. The proposed sensing platform contains one ultrasonic rangefinder and two arrays of six passive infrared sensors (Melexis MLX90614) connected to a microcontroller unit with different components such as an SD card reader, energy monitoring circuit, and flash memory.

The review reveals that magnetic sensors are appropriate for length-based vehicle classification. This is very relevant in the context of this research as the collector roads are mostly occupied with smaller vehicles and a volume to capacity ratio doesn't fit well.


a
b
c
Weather Cape
RF Engine
RTC Unit
RS485 Transceiver
Power Management
micro SD Card
iVCCS$_{G1}$ PCB (Bottom)
iVCCS$_{G1}$ PCB (Top)
Pavement Temp
Ambient sensor
Magneto-meter
Accelero-meter
Embedded Controller
GPS Module
XBee