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A Review of IoT Application in a Smart Traffic Management System

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***Abstract*—This paper explores the advancement of smart traffic management system using the Internet of Things (IoT). It works as middleware on the foundation of the IoT and augments the idea of the smart city through the traffic light control, smart parking, smart emergent assistance, anti-theft security system, and others. IoT provides an effective way of interactions among the web devices with the traffic embedded sensors, services, actuators, and other interconnected networks. Hence, the application of IoT in the smart traffic management system is not only limited to the reduction of the traffic congestion, air quality improvement, and traffic flow optimization but also extended to the continuous monitoring and ensuring the security and safety for the elderly people. Acquiring multiple sources of traffic information for data analysis, IoT monitors the traffic flow, controls the traffic operation and stores the correct decision for the future information presentation. Having a combination of advanced machine learning approach and data-driven technique, there are implementation limitations of this technology. However, this survey provides a good insight into the application of IoT in the smart traffic management system based on the existing research perspective.**

***Index Terms*—Internet of Things (IoT); Artificial Intelligent (AI); Global Positioning System (GPS); City's Transportation System (CTA); Geographic Information System (GIS); Intelligent Transportation System (ITS)**

I. Introduction

The traffic management system of a metropolitan city is a keystone for urban mobility. With the rise of the population, the demand for vehicles grows up and hence the requirement of transportation has also increased. Infrastructural development becomes an indispensable part of complementing the population growth to augment urban mobility. But the traditional traffic management system is shown not only ineffective for accompanying the increased number of vehicles with the use of police control and traffic light system but also incompetent enough to handle this growth of traffic on road systems [1]. This traffic congestion consequentially consumes precious working time for being incapable of handling extensive traffic congestion and eventually leads to the environmental pollution for an extended period of vehicle emission. Brussels, the capital city of Belgium, is considered as one of the most traffic overcrowded cities, as stated by Forbes [2, 3]. Adequate pre-measures and proper planning can help to reduce the number of traffic problems and manage an increased number of vehicles on the street. For instance, the cars on the road are waiting for a green signal although there are no cars on the street. Therefore, periodic traffic light change is not a viable solution, and hence, IoT-based traffic control system is required to integrate with the existing traffic management system. Using public transport instead of private cars can help to reduce the traffic problems to a certain extent. If the number of people increases, the necessity of public transport will increase, which will turn on the same problem. Moreover, the safety and security of traffic mobility and pedestrian walkability are paramount to improve all the possibilities in the traffic management system. The IoT-based traffic system considers all those aspects at hand, is welcomed as a substitute for overcoming the limitations of the existing traffic system and introducing an efficient one [2, 4–6].

Fig. 1. Traffic system.

Due to the scope of application in computing architecture, knowledge of handling the device data management and processing technique, IoT can apply in real-world problem solution where decentralized devices are continuously subscribing the center hub for computing a standardized way to implement the resource allocation and decision-making problem. The introduction of IoT can reshape the data management system of the transportation industry by using AI algorithms for fast data processing in a complicated situation in the presence of new dataset related to the transportation system. Moreover, IoT can provide the processed data by analyzing the traffic condition and predict user-required information by adopting a deep search in the present colossal data volume [2]. Lack of synchronization in a real-time scenario introduces the backward problems in the current traffic management system and leads to the cascading data missing to the progressive user end simultaneously. IoT performs the data acquisition from the collection, supervises during the transmission, and evaluates

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for the next cycles. Although the scattered data coming from individual enterprises, IoT connects labeled data accordingly in a traffic information system. All these advantages make it preferable for smart traffic management system where it can establish communication between a centralized processing unit with multiple different groups [7].

The advances of technologies and the uncertainty in the decentralized data streaming system make the traffic management system as an indeterministic approach. Hence, it is a challenging task to solve the problem following a particular procedure. This paper explores an IoT-based smart traffic management system by considering the advantages of sensor fusion technique for autonomous car and image data streaming from multiple cameras from different parts of the traffic system. Vehicles data are broadcasted independently to the center hub. Using data-driven technique, data processing performance for the priority-based traffic light control system has become the leading sources for decision making. In each case, the sensor and camera data are the eye, and ear for the information receiving from own sources and data-driven approaches work as a brain for decision making in IoT. The significant advantage of IoT is to reduce the manual work of local traffic police and give the user a piece of more updated and intuitive information by ensuring the persistent autonomous data transmission instead of manual technique (shown in Fig. 1) in the real-time traffic system.

The writing of the remaining parts of this research work is as follows — the literature survey has been discussed in Section II. Section III has presented the idea behind smart traffic. The feature application of IoT in the traffic system has proposed in Section IV. The example scenario of smart traffic system has analyzed in Section V. Challenges and limitations of IoT-based smart traffic system have identified in Section VI. Finally, the concluding remarks and future direction have provided in Section VII.

II. Literature Survey

In a smart city, like other urban limitations such as water and waste management, intelligent buildings, energy, education, policing and governance, optimal traffic management system benefits the citizens in their mobility by the cost minimization and the resource maximization. Application of IoT in this system provides a rational solution for the urban challenges [8].

The IoT is composed of interconnected electronic equipment such as smart devices and sensors via the internet (shown in Fig. 2). The devices exchange information and pass controlling instruction to each other through the internet and/ other communication protocols such as Wi-Fi, Bluetooth, etc. All appliances are connected to a centralized data hub for further information processing to decode the received data and new decision making. Since the collected data are enormous and the information are required to convert into the human interactive interference, a hi-tech cloud computing is required to gather data, process information upon various features and make the instruction as per the requirement of the end-user

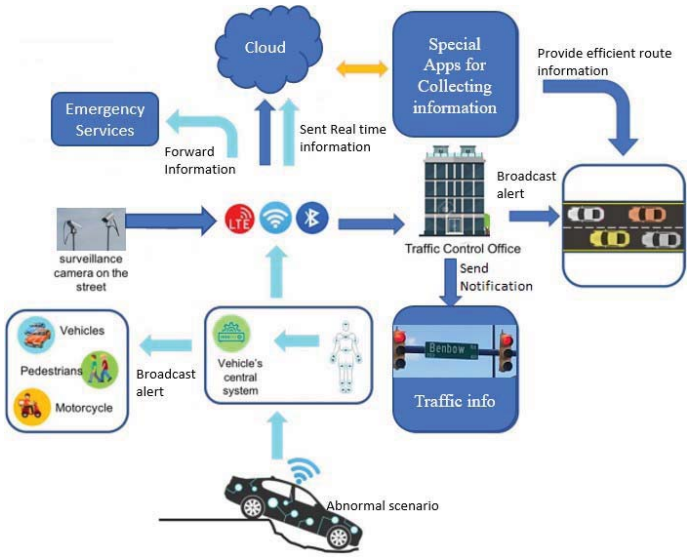

Fig. 2. Overview of IoT in traffic management [9]

following the big data analysis. As an example, in a smart traffic management process, the data regarding streets, car GPS location, traffic light, car speed, and other information are necessary to be filtered, pre-processed, stored and analyzed to transfer into the knowledge of the decision making [7, 8]. The following equation describes the overall IoT information.

$$IoT = Real - Time\ Physical\ Information + Appliances + Networking\ Media \quad (1)$$

A public transport system has discussed in [10] where IoT implemented as a communication mean to connect with the end-user for the information sharing purpose. The person positioning at different places such as bus stoppage, workplace, home and/ street can access information at any time about the current location of the bus, seat availability in the bus, and other details on the bus. All these information access can be done through the internet and other technology such as GPS, RFID, and controller with Wi-Fi module (shown in Fig. 3). GPS tracks the current location of the transport and transmit this information to the hub using any network protocol via the internet.

In [11], a wireless sensor network system has proposed for vehicle classification and a large volume of traffic control using IoT. The system consists of wireless gateways to the cellular network, cloud information storage and computing, wireless routing gateways, and real-time data subscribing sensors. The proposed IoT-based wireless sensor network has installed beside the roadside ongoing traffic system for traffic flow monitoring as a benefit of low maintenance and semi-autonomous system handling technology.

In [9], sensor integration technique has been planned for all vehicles to attain a sustainable Intelligent Transportation

System (ITS). The purpose of sensor fusing is not only to control traffic vehicles to ensure a planned traffic regulation but also guarantee safety and security in different parts of ITS. The onsite traffic officers have used smartphones in [12] to dynamically control the traffic flow using the IoT-based traffic management system. For example, an IoT-based traffic control system is partially implemented in Makkah, the holy city of Saudi Arabia, due to the constant visitation for the pilgrims around the year.

In [2], traffic uncertainty has discussed due to the lack of administrative personnel's performance, traffic signal limitation, inadequate road infrastructure, and so on. This work has visioned its long-term effect on economic development,people lifestyle, etc. Therefore, several applications of IoT devices have discussed in the adaptive traffic control system by using a wireless sensor system, video analysis, etc.

The valuation of dynamic road safety assessment has discussed for a specific period in [13]. By proposing a cost-effective IoT architecture for real-time computation, a scalable metric has proposed for ensuring road safety. Therefore, Hidden Markov Models (HMMs) are computed to safety routing path in the proposed architecture using machine learning concept.

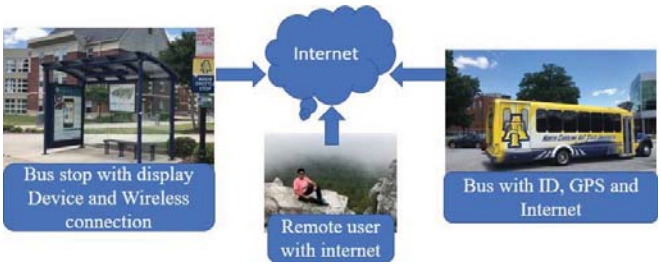

Fig. 3. Architecture of smart public transport system.

III. Idea Behind Smart Traffic

The primary objective of IoT is to connect "Things" in real-time such a way that all traffic information is updated simultaneously and effectively. It can play a significant role by routing and collecting information from different sources such as sensors, cameras, GPS, etc. All these data are used to find the traffic pattern following the data-driven technique and train data set by using AI algorithms to simplify the model system for enhancing performance and future research feasibility. The center hub processes these data for labeling and clustering in a different category based upon the feature selection from various sources, and then connect to the websites for recognizing the emergency condition and providing service to the end-user in real-time. For example, real-time GPS information helps traffic light management system to direct the flow of vehicles for avoiding traffic jams. Also, the remote users are aware of the shortest path and minimum time to reach the destination. Moreover, traffic control camera system gives more information using image processing technique about the safe traffic movement [14]. All these data acquisitions help the user to make the best decision, which alternatively reduces traffic violence and enforce the security of the traffic system. The possible approaches to optimize the traffic issue and increase system management performance by considering the following topic described below:

A. Acquisition of Multiple Sources of Traffic Information

The multiple sources of traffic information such as LIDAR, camera, sensor, etc. are the mixture of statics and dynamics, and they are streaming information continuously which may or may not change over time. After receiving these data, they are classified, labeled, and stored in the center hub for the further feature extraction and decision-making purpose.

B. Traffic Data Analysis

The received data are analyzed to improve the traffic conditions, performance, and congestions to get real-time and reliable insights about the optimum traffic management system. The correlation among old data can be established using a data-driven technique to model and apply the information for other cities. These help people to find an alternative route, which in turn help to decrease traffic jam and approximate the shortest time to reach the destination.

C. Monitor and Control of Traffic Operation

The centralized management dashboard provides a summary of collected information from different sources across the country and depending upon the features, organize them using AI to reduce the traffic jam. Geospatial map considered as one of the most critical data sets to extract the behavior of traffic flow and identify the substantial traffic area using the data-driven technique. This information can be used to find the official, school, and/ other busy areas and hence implement traffic control technique by connecting users to reduce the traffic load for the peak traffic hours.

D. Information Presentation from Data Storage

Geographic information system (GIS) is an essential city transportation presentation for the graphical display of unusual traffic density, speed of the vehicles, number of accidents, etc. The robust control is designed initially from storage information such as cameras, traffic lights, and other traffic system-related data and later update the control system using IoT to the change in the system information over time.

IV. The Feature Application of IoT in Traffic System

The future IoT application makes researchers interested in applying to the smart traffic system. The advantage of IoT is that it is ecosystem friendly and can utilize the maximum data features extracted from the individual users by classifying them as the labeled data. Moreover, it can continuously track the error to upgrade the system data handling performance. In 2018, around 367 projects accepted as megacities where IoT is considered in the traffic management system to improve the health of the city environment and also people lifestyle [4–6]. The feature application of IoT in the traffic control system can develop the best traffic mobility. The maximum usage

of multiple resources in the traffic control system enhances the best transport routing option. Although around 61% of the world population is predicted residing in the metropolitan cities by the year 2032, the planned IoT-based traffic optimization ensures the ideal usage of traffic flow control during that period [15, 16].

A. Reduction in Traffic Congestion

The application of IoT in the traffic management system can upgrade the conventional traffic control system into a smart one. Its use is not limited to ensure reliable communication and also provides an automated system management concept for reducing traffic congestion. Although the affinity of private transportation causes an immense amount of traffic congestion, the traffic management systems of some countries are trying to utilize the information from CCTV for smooth traffic operation. A well-organized traffic system transmits vehicle information to the traffic management centers for the proper flow of vehicles with no idle vehicles in massive traffic scenario.

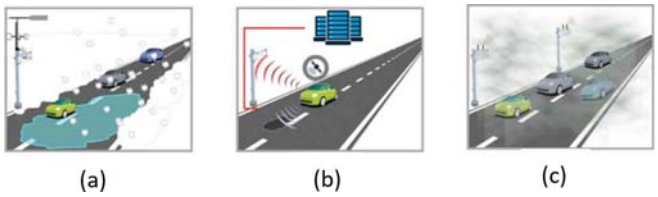

Fig. 4. Environmental category for air pollution (a) street weather; (b) street surface and (c) air pollution [9]

B. Air Quality Improvement

Air quality can be improved by reducing the traffic load and hence decreases the pollution density for a specific area. The researchers design devices which are embedded in the traffic light system such as in Las Vegas to monitor the air quality and control the traffic light when there are lots of carbon-dioxide detected in a particular traffic lane (shown in Fig. 4). Moreover, the IoT connected devices are scaled down such a way that it can easily be fitted in any traffic-controlled box to monitor the air quality information to the centralized hub-system. The car maintenance costs are also lowering as a tenth by exploring the eco-friendly device application in the industry [4–6].

C. Traffic Flow Optimization

The application of IoT in driving safety and vehicle control makes the system collision-free by utilizing the predicted model among the shared devices. A perfect example of traffic flow optimization in Las Vegas for the embedded sensors in the traffic light system (shown in Fig. 5). The purpose of this project is to implement the machine learning technique at an intersection in an area of downtown using IoT-based sensors. These recorded weekly sensor data about the traffic flow and the number of pedestrians transfer to the central hub. Hence, using machine learning data-driven technique, the system intuits the traffic patterns and predicts the future

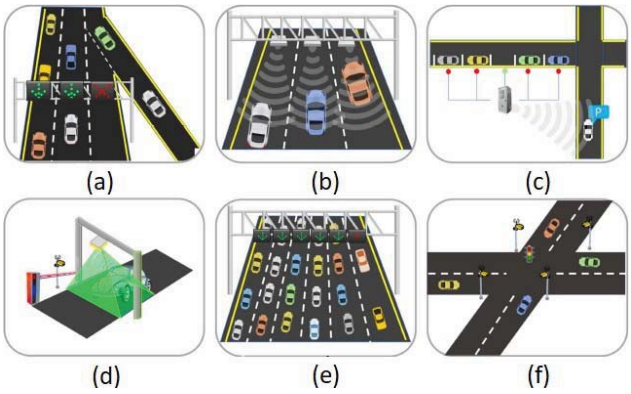

Fig. 5. Traffic flow optimization using IoT [9]

traffic light control policy to optimally guide the traffic flow for overcoming the traffic congestion problem [4–6].

D. Improving Law Enforcing and Easing Government Services

The city under camera surveillance and roadside data monitoring system can help the law enforcing agency to enhance the traffic security system (shown in Fig. 6). San Antonio is an example of this approach. Although the city area around 460 square miles, the availability of the video court monitoring system throughout the city eases the traffic control violence. In addition to that, the administrative authority can quickly help the victim if the significant occurrence happens on the road [4–6].

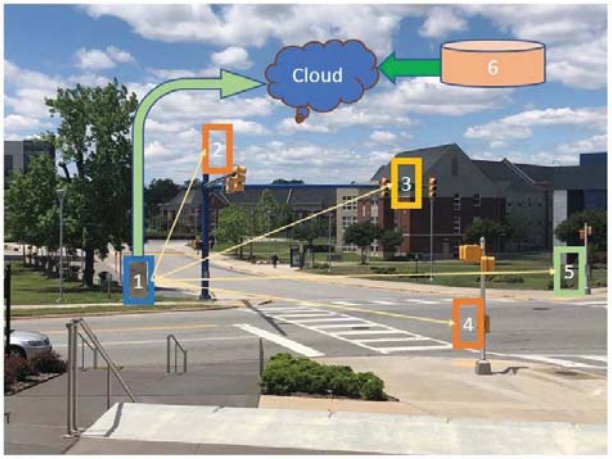

Fig. 6. IoT-based traffic security system

E. Easing the Elderly Life

The IoT-based traffic control system provides opportunities for older people having easy access to healthcare facilities, cultural activities, and others. All these help the older people to change their notion to society and allow leading an independent life. In public transport, the availability of sensor

data provides continuous security to the senior citizens and help them to go for a long distance with the help of auto voice and sign detection system. Since the IoT ensures a frictionless transportation system, the vehicles are connected and confirm the experience easier for them. Also, IoT provides a centralized payment system using the card or any smart android devices. Therefore, the older person can easily buy tickets using voice, touch, or other more comfortable ways. For example, in Chicago, the Ventra card payment system helps older people to use local transportation easily. Also, with this card app, they can ride any vehicles as their own choice [4–6]. Moreover, the official arriving and departure time announcement by the IoT connected devices helps them to avoid long waiting in the station.

V. Example Scenario in Smart Traffic System

Undoubtedly, considering traffic management as an infrastructure challenge faced by the present world nowadays, some developed countries have already implemented IoT and big data partially to minimize issues such as traffic light control, smart parking, emergency assistance, and anti-theft security system in some of their cities.

A. Traffic Light Control

The IoT-based control system uses real-time traffic information for controlling the traffic loads by changing the traffic signals. The mounted sensors and cameras at strategic traffic junction collect vehicle density of the roads and divert the vehicle direction by changing the traffic signals frequently. Using the big data analysis from the stored data, the traffic controller starts to regulate the traffic signal from a reasonable distance to ease the traffic congestion at the junction area. Since the vehicle density depends upon the weather and the traffic hours, the weather sensors set close to the traffic signals also control the traffic lights to direct the vehicle routing path accordingly. Besides, to avoid the dimming light problem during the day-night transition period and even the weather is changing, the roadside signals are also controlled by IoT to instruct the drivers about the traffic lights from a long distance [8].

B. Introduction of Smart Parking

The application of IoT in the traffic control system not only focuses on traffic congestion reduction but also helps drivers to find a safe parking place without hampering the vehicles transportation system. Present statics from the Intelligent Transportation Society of America shows that 30% of traffic jam happens due to the drivers who are looking for car parking spots [4–6, 16]. The IoT-based cameras and sensors can provide real-time information of empty spaces in a parking lot to the forthcoming cars towards the parking area. European city like Paris, France and US state like Kansas are the examples of the smart parking system where remarkable improvements in the traffic system observed due to the introduction of the intelligent parking systems from the first year [8]. The spatial sensors detect the empty parking spaces and hence provide information to the nearest work station through IoT-based internet system. In this system, it is not necessary that knowledge will transfer directly from sensors to the remote hub but also the data hopping can be possible among the sensors and the autonomous cars. Moreover, the intelligent system allows drivers to reserve the parking area online during their travel time [2].

C. Smart Assistance during Emergency

Road accidents are prevalent across the world due to the lack of safety and security in the traditional traffic control system. The IoT-based system keeps the accident area in the record and provides additional information to the next drivers for the careful driving in the accidental location. However, after taking all the necessary measures if an accident happens, unfortunately, the fastest emergency support is possible due to the roadside cameras and the embedded sensors mounted close to the mishap area [8].

D. Provision of Anti-Theft Security System

Due to the continuous monitoring of traffic cameras and embedded sensors, IoT can easily determine the missing vehicles and the necessary information such as the location of the cars. Moreover, the vehicle functioning system can be stopped immediately using the online information system. Both the wireless and/wired charging [17–20] or mechanical fueling system require electrical power sources to consume energy for the car auxiliary startup. A range of pre-caution level can be set through the online internet-based system to turn off the battery power and hence prevent the functioning of the missing vehicles, although the tracking system will be continued using the solar energy [2, 21].

VI. Challenges and Limitations of IoT-Based Smart Traffic System

Although IoT-based smart traffic system provides the maximum opportunity using the machine learning data-driven technique, there are several disadvantages and the implementation limitations in this system. Firstly, infrastructure issues such as road zoning, planning, and other construction-related concerns become significant problems for implementing this technology. Secondly, high-speed internet-oriented data transfer media is required to get the full applications of the IoT-based traffic system. The network unavailability or instability for any reason may disrupt the entire traffic control system [8]. Therefore, overall data management would be a big challenge for this traffic management system. Thirdly, many devices are accessing the central network, which increases the chances of hacking and malfunctioning the system. A top-notch security layer is necessary for making an impenetrable and hack-safe smart traffic application. Personal data should not open and well maintained with proper protection while using for traffic management [4–6]. Hence, secure data management should highly focus on implementing these high-tech applications. There are also some other social abstract concepts (i.e. norms, values, etc.) are difficult to implement during driving in the IoT-based traffic management system. In addition to that, the overall system is information-based and decision making is

followed by using the data-driven technique. It is possible to observe the unwanted situation in an uncertain scenario which is uncommon for the traditional traffic system.

VII. Conclusions and Future Works

Any city's livability and progress largely depend upon the traffic system. Therefore, the increase of vehicles with the rise in population will not be a matter at all if the smart traffic system is implemented using the IoT-based technique. Since the number of cities is increasing day by day, machine learning-based data-driven method and AI can play a promising role in the integration and development of smart services in the presence of infrastructure lacking. Its growing facility inspires the researchers to extend its implication to the overall lifecycle of the vehicle production system.

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