International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 6 Issue 5, July-August 2022 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Review: Smart Traffic Management System

Bharti Kumari[1], Vinod Mahor[2]

[1]M Tech (Scholar), [2]Head and Assistant Professor,
[1,2]Department of Computer Science and Engineering,
Millennium Institute of Technology, Bhopal, Madhya Pradesh, India

ABSTRACT

The number of automobiles on the road will only increase due to the ever-increasing population development in urban areas across the world and manufacturers' ongoing manufacturing of all types of vehicles. This inevitably causes additional traffic congestion, which is exacerbated during rush hour and especially in big urban areas. Urban planners, local officials, and academics are continuously under pressure from this phenomenon to find methods to make traffic management systems safer and more cost-effective. Numerous researches have been carried out to solve this ongoing issue, leading to some major advancements like specific lanes for emergency vehicles in metropolitan areas. Even with these lanes, it is sometimes challenging to meet the appropriate goal timeframes for emergency vehicles to arrive at their locations. Intelligent Transportation System is a fresh approach that aims to solve this problem (ITS). By fusing present infrastructure with existing technologies, this approach can aid in problem-solving. In this paper, three alternative traffic management techniques: RFID, Internet of Things, and Traffic Light Systems (TLS), which can be static or dynamic (IoT). In the latter approach, traffic data are swiftly gathered and delivered to Big Data for analysis, while mobile applications, also known as User Interface (UI), are used to evaluate traffic density in various places and offer alternate traffic-relief suggestions.

KEYWORDS: *Intelligent Traffic System, Internet of Things, Smart Traffic Management system, Wireless Sensor Network*

How to cite this paper: Bharti Kumari | Vinod Mahor "Review: Smart Traffic Management System" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-6 | Issue-5, August 2022, pp.1118-1125, URL: www.ijtsrd.com/papers/ijtsrd50595.pdf

IJTSRD50595

I. INTRODUCTION

Traffic congestion is still a serious problem that affects municipal politicians, commuters, citizens, and urban planners in developing and metropolitan centres all over the world, especially during rush hour. Traffic congestion has a wide range of effects and repercussions, from slower economic growth to higher fuel use and air pollution. Traffic congestion will only continue to offer additional barriers and challenges for economic progress while having a detrimental effect on quality of life as the number of vehicles on the roads rises. As a consequence, individuals will inevitably gravitate toward moving to locations that are safer, more efficient, and less congested with traffic. The task of designing an effective traffic management system that can meet the demands of a big metropolitan region while also being readily adaptive to population development is made significantly more difficult by this[1-2].

The discipline of traffic management has benefited greatly from the use of frequency identification (RFID). More than 50 years have passed since the invention of the technology that powers RFID [3]. This method enables solutions for extensive demands in automatic vehicle identification that are both affordable and simple to use. RFID can considerably lower the cost of expensive infrastructure. Although there are numerous additional applications for radio frequency identification, traffic management systems have been one of its most effective uses. Additionally, RFID is used in many aspects of traffic management, including parking management, vehicle detection, identification, security, and tracking.

Urban traffic congestion is addressed via the Traffic Management System (TMS). Smaller systems have initially been installed at a number of locations across the city. New approaches, techniques, and technologies are developed throughout time, and new features are added to the current system to increase its effectiveness [4-5]. We lack the data necessary to make a comparison between the final system's improvements and the beginning condition (without a traffic management system). As was previously indicated, traffic lights may be used to manage traffic congestion. When correctly coordinated in tandem, traffic lights may reduce car accidents and improve traffic congestion, which is a crucial part of traffic management. John Peake Knight created the first traffic light that was manually controlled in [6], while Lester Farnsworth Wire created the first automated traffic light [7].

Fixed Cycle (Static) TLS was more extensively employed in traffic control systems in the past and had greater popularity than Dynamic TLS [8]. Fixed Cycle TLS was ineffective because it increases traffic density and congestion, particularly on roads where there was already a lot of traffic flow to begin with. This is particularly evident in nations like Malaysia where Fixed Cycle TLS use is pervasive. By altering the traffic pattern dependent on the amount of cars on the road at any one time, a dynamic TLS can significantly decrease this congestion.

Additionally, modern technologies in the fields of wireless communication, control systems, image processing, and data mining have integrated with the existing transportation and street infrastructures in addition to the traditional traffic control systems, implying the next level of smart and intelligent facilities known as Intelligent Transportation [9].

Systems (ITS). The development of communication has recently led to the emergence of a new field known as the Internet of Things (IoT), which has attracted particular attention from both academia and business due to the variety of platforms that can be connected and communicate with one another under this paradigm.

II. RELATED WORKS

One of the most significant Internet of Things (IoT) applications that is facilitating the growth of smart cities is Intelligent Traffic Systems (ITS). Numerous researches have been done with the goal of bettering traffic control. The Green Wave System is a method that has been researched in which an approaching emergency vehicle can cause the traffic signal to turn green as the vehicle is crossing the junction. Additionally, the position of rescue vehicles may be found via image processing [8]. With this technique, a rescue truck will always see green lights along the road and won't be stopped while travelling to its destination. This method also makes it simple to identify any stolen cars that happen to be driving through the junction at that moment. The biggest drawback of this approach is that it displays erroneous information regarding the position of emergency vehicles during bad weather. The picture that the camera obtains is affected by noise due to wind, fog, rain, and snow, which leads to several errors when determining the precise location and identification of cars. RFID can assist to provide more suitable synchronization in order to remedy this flaw [10].

The tags used in Radio Frequency Identification (RFID) serve as labels and are fastened to the items that need to be recognised. RFID tags operate independently of any battery or other power source. Instead, an RFID reader is used to deliver the pertinent information to them [9]. Because they are included into the dashboards of cars and other vehicles during production, RFID tags are frequently undetectable to human sight. The concept behind the RFID system is that in scenarios involving emergency vehicles, an ambulance would be fitted with an RFID tag, and a reader would be set up in the traffic system. As the ambulance approaches a traffic light system, the reader's job is to scan all the incoming data from the RFID tags and identify it [11]. The disadvantages of this technique have not received much attention in numerous works up until this point. For instance, would the light change to green to enable the ambulance to pass through the crossing in the absence of an emergency or the requirement for a quick response? In several of the study articles I have seen, the answer to this issue is not stated in detail. However, in the actual world, if there wasn't an emergency requiring an urgent and quick reaction, ambulances or other emergency vehicles wouldn't have any precedence to pass through a junction [12]

One study suggests using a system known as a Wireless Sensor Network (WSN), which makes use of magnetic sensors, to increase the precision of vehicle detection [13]. One of the most crucial system functions to be taken into account is vehicle detection. Why is this task so crucial? when automobiles are precisely identified, the information transmitted to the traffic control system is similarly precise. This enables the system to handle traffic flow, lane occupancy, and vehicle speed detection more effectively. In this model, the system makes use of the unprocessed data to choose a threshold that permits more precise vehicle detection [14]. The Signal-to-Noise Ratio (S/N) is a measurement that has to do with the system's worst flaw. If this parameter is set too low, it might have a negative impact on the accuracy of vehicle detection. For example, it could lead to more false alarms being sent or more missed detections as a result of subpar system operation.

Magnetic and infrared sensors can be employed together to enhance vehicle detection and the detection system's overall effectiveness [15]. However, the biggest challenge they encounter with this procedure is the trajectory of approaching cars, particularly in work zones. Magnetometer detectors were used for vehicle identification in intelligent transportation systems [16]. (ITS). The local magnetic field that is produced by a magnetic detector is partially distorted as a vehicle approaches it. The whole local magnetic field is warped whenever the vehicle is between the final and middle part of the magnetic field produced by the detector. The data is then sent to a controller after it has been received from the detectors. This controller's primary job is to monitor and assess the direction of incoming traffic before using the data to concurrently operate the traffic signal systems at several junctions [15-16].

Mobile-based traffic measuring systems have also been proposed as a method of reducing traffic congestion. This technique makes it possible to monitor and control road traffic congestion. This system's seven levels, which start with the individual smartphone and go all the way up to the top-level business model, can finally enable the determination of all the different components of traffic on highways. The mobile application will then be able to assess how long a person would be delayed due to traffic, get information about the congestion on specific roads, and recommend workable other routes, approaches, and other improvements. A novel paradigm for an Intelligent Traffic System was put out by Badura and Lieskovsky [17-18]. Here, the cameras placed at the intersections scan and keep an eye on their immediate surroundings. For general image analysis, the captured data is instantly transferred to a topology independent data delivery system. The function of the data delivery system is to ensure data transfer through mobile Ad-hoc network and to offer the communication framework (MANET). They have experimentally proven the viability of real-time data transfer in a variety of circumstances.

Photoelectric sensors were suggested by Salama et al. [19] for managing traffic signals. The precise locations for installing sensors are one of the most important factors. This is mostly due to the traffic control department's need to track the movement of cars at specified times, particularly during rush hour. Data from the sensors is input into an algorithm at the traffic control centre, which assigns a relative weight to each road, using the obtained data.

When one side of a road is busier than the other, the system will open that side's traffic lanes and allow more time to move vehicles than it would on a less congested route. In extraordinary cases, this technology can allow human involvement to reduce traffic congestion. The methods section will take into account the specifics of photoelectric sensors.

III. RESEARCH METHODOLOGY

There are three designated kinds of vehicles in the Intelligent Transportation System (ITS) in order to implement it properly: regular cars, stolen vehicles, and emergency vehicles. These classifications are flexible and can be altered as needed. System priorities can be divided into three categories: lowest, highest, and highest. For dynamically updating the database with Short Message Services, we require these two crucial criteria (categories and priority of vehicles) (SMS). A database may be used to hold all the information about the cars going through junctions in addition to their classifications and priority. This method offers a situation where this most recent data may be used for traffic monitoring in later phases. Readers can be of great assistance to us in resolving the issue of the direction of the stolen car. They can be put in place before every intersection with a traffic signal so that the direction of a stolen automobile can be quickly identified. However, rain or strong sunshine seem to be the major causes of problems for these readers. In these circumstances, reader signals will be corrupted[20].

Two key systems—the software system and the electronic system—are used to deploy ITS on the road [21]. The software system includes cloud server, control system, green light algorithms, and various apps for monitoring traffic congestion for traffic cops. While electronic systems also include connections between sensors, microprocessors, and traffic lights. The first step in reducing traffic is to identify and gather statistics for each route bound. Inductive loop detectors can successfully assist us in achieving this aim. The first phase is successfully finished when these data, which were gathered from chips or microprocessors to Base Station (BS), were transferred to BS via Wi-Fi. The next step is to figure out how to create a practical algorithm that can compute Green Light Phase Time (GLPT) using the data that has been received and saved in the database [22]. Each road's GLPT information is sent from the BS to the CPU. The microprocessor now has all the information required to change the GLPT of each road bound. Additionally, traffic cops might benefit from this circumstance and see some GLPT-related modifications on the traffic light monitoring programmes. The whole explanation of this process's algorithm may be found in [23].

The core algorithms of green wave and the identification of stolen automobiles are provided in the two Figures that follow [24]. The letters "H" and "HT" in flow chart 1 represent the categories "high" and "highest," respectively. When organising the priorities, highest priority (HT) takes precedence over high priority (H). The vehicle with the greatest priority is given priority if two cars are approaching the traffic signal junction simultaneously from the opposite direction. In addition, the vehicle that arrives first is granted priority if two cars have the same priority.

In Figure 1, the driver of the car receives the destination's information and chooses which intersections to take to get there. The purpose of the Global System for Mobile Applications (GSM) is to upgrade a vehicle's priority to "H" or "HT" and to provide information about the position and quantity of intersections that must be crossed during this phase [25].

When a vehicle's priority is set to "H" or "HT," the system sends out signals to change the colour of the traffic light to green at the Nth intersection before reducing N to N-1. There are two possibilities whenever N is reduced: The car has arrived at its destination if (a) N is less than zero, and it must proceed to the next intersection if (b) N is equal to or larger than zero. With the aid of a reader deployed 200 metres prior to the junction, we can confirm whether the car has reached at that junction or not. To change the traffic light system's colour to green at the Nth intersection, these data are supplied to the traffic light. Until N is adjusted to less than zero, which indicates that the vehicle has arrived at its destination, this process will be repeated several times [26].

The process for identifying stolen vehicles is shown in Figure 2. The user will first send an SMS with details about a stolen car. The system will then modify its database and set the priority of the stolen car to "T." There are now two possibilities: a car has GPS technology. In this instance, it is possible to pinpoint the precise position of the stolen car. The Police Department receives this information. When an RFID reader identifies a stolen car, it communicates the position of intersections where the vehicle was traced in case (b) the vehicle lacks a GPS, which can be very helpful.

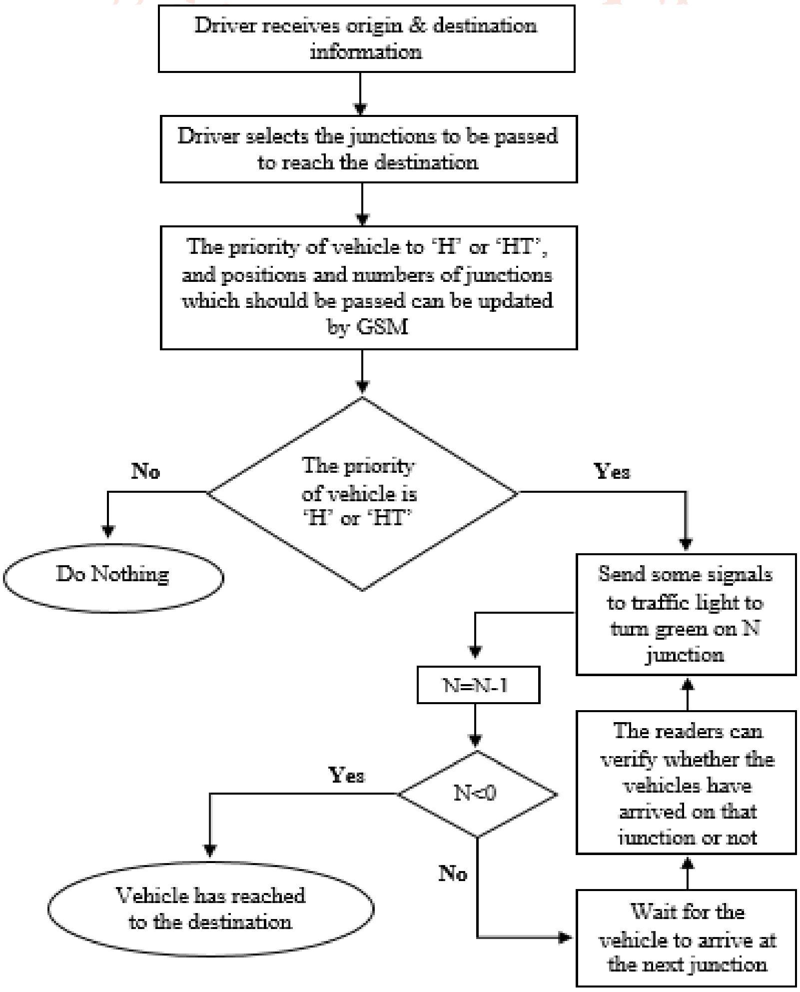

Figure.1. Blue Flow Systems

The majority of traffic light systems used IR sensors, IR transmitters, and IR receivers connected in series. As soon as a vehicle approaches a junction, it is identified; the traffic volume is then assessed, and the traffic lights are adjusted as necessary, depending on the signal frequency or density. Floating Car Data (FCD), also known as floating cellular data, is another helpful method for estimating traffic speed and congestion. This approach depends on a number of factors, including the gathering of localization data, speed, direction of travel, and time information from GPS in moving vehicles [27]. As a result, any moving car that has a mobile phone in use serves as a kind of road sensor. It can measure trip times, determine traffic congestion, and produce traffic reports for the police department. This method has the benefit of not requiring any additional hardware or devices for FCD. Every mobile device that is turned on acts as a traffic probe and a source of anonymous data. There are three sub-systems in the FCD. The probe vehicle and a geo-location unit are part of the first subsystem, which is referred to as the probe system. The second is an online database that compiles all the necessary traffic information and overlays it on top of a digital map. The third subsystem is the web client, which is intended to serve as a User Interface (UI) for quickly retrieving traffic data [28].

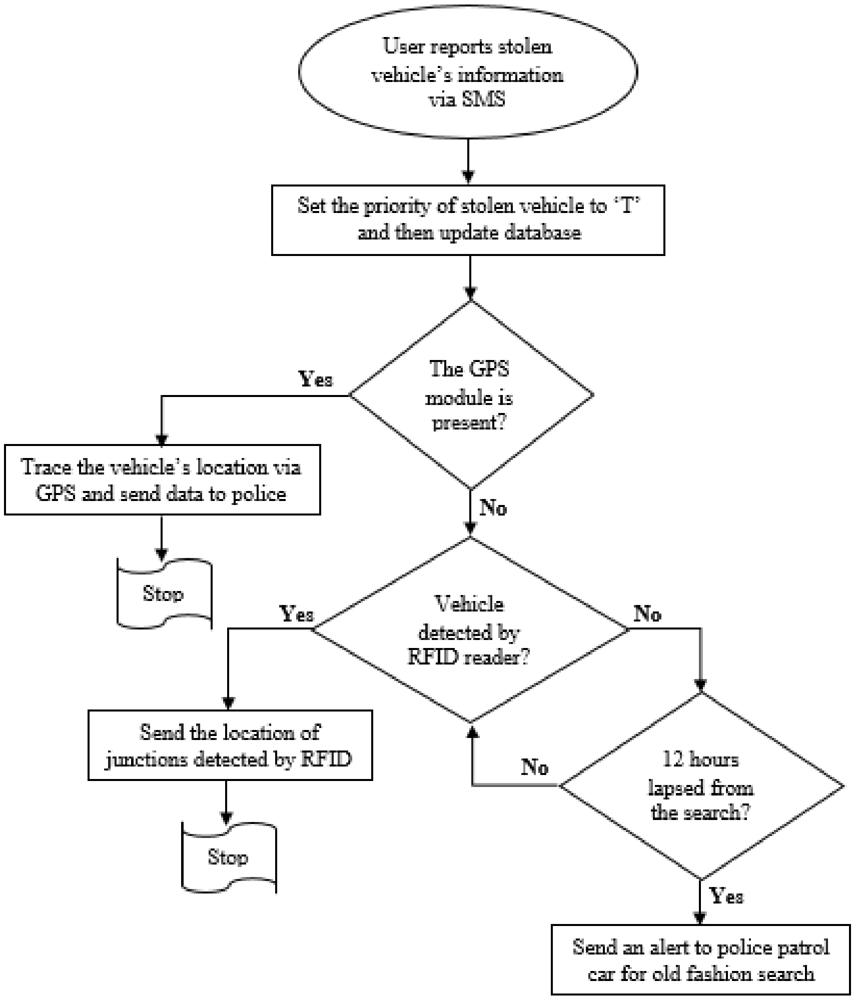

Figure.2. Procedure for the detection of stolen vehicles

One of the four techniques shown in Table 1 is utilised to collect raw data. Due to the fact that it is utilised to calculate the probing velocity of vehicles, the geo-location data is quite helpful. As previously stated, a smart phone is all that is necessary for FCD and no further hardware is needed. Using this smart phone

attached to a probe vehicle for measuring the locations of the probe vehicle as well as calculating the vehicle's direction and speed. Finally, a wireless network is used to communicate all of this data to a server using a relatively straightforward HTTP request. All of these data will be given an acquired time tag on the server side.

Another method to reduce traffic jams has been proposed [20] and uses video processing to collect data from cameras with feedback mechanisms. This is a crucial consideration if there is a large amount of traffic congestion. The system features a video camera on each side of a four-way intersection or four cameras above the red signal. Either camera records a video, which is sent to a computer, where an algorithm for image processing calculates the amount of traffic on each side of the road and switches the traffic lights appropriately. The hardware and software components of the video processing approach are listed below. The purpose of the camera is to establish a connection between the server and the actual traffic scenario. The system can then adjust the requirements for this procedure based on the input it has received. The software toolbox [25, 26, 27] includes algorithms for image processing, analysis, visualisation, and C++ compilers.

Salama AS et al. have proposed one such development. The usage of photoelectric sensors is a part of [29]. To gauge the volume of traffic in this system, the sensors look for changes in the road's weight. This information is incorporated into an algorithm that a neighbouring traffic control tower uses to regulate traffic lights[22].

based on these facts. The technology can allow for the opening of traffic congestion on roads that have a larger relative weight depending on the readings of the photoelectric sensors by changing the frequency at which traffic signals change. This system's adaptability is an extra bonus since it may be used in special circumstances that call for little to no traffic congestion, including the passage of emergency vehicles [23]. The application of radio-frequency identification (RFID) technology can be used to achieve this. In general, this method permits the maintaining a generally smooth traffic flow while being flexible enough to respond to particular circumstances that arise on particular roadways that the system is watching. Additionally, the suggested system may be configured to either require very little human interaction or greater human engagement for optimal control in specific circumstances[30].

S.N.	Method	Description
M1	Traffic Management System (TMS)	This method is a top-down management approach that incorporates technology to enhance safety and traffic flow. The task is broken into smaller systems that are placed in various locations in this case. For the purpose of enhancing traffic flow, real-time traffic data is collected through cameras and speed detectors and sent to the Transportation Management Center (TMC).
M2	Green wave system	In this method, an approaching emergency vehicle causes the traffic signal to turn green anytime the vehicle is approaching a junction. More precise emergency vehicle position detection can be achieved through the use of image processing. A result of this is that an emergency vehicle will encounter only green lights along its path and won't encounter any halt as it travels to its destination.
M3	RFID tags	Since radio frequency is unaffected by weather, this method solves the severe weather issue in the green wave system. RFID tags are integrated in the ambulance's dashboard, and RFID readers are placed 200 metres from intersections. The ambulance will be detected when it approaches traffic signal systems by the RFID reader, which will read all the data from tags.
M4	Wireless Sensor Network (WSN)	This method increases the precision of vehicle detection by using a group of magnetic sensors. The local magnetic field that is produced by a magnetic detector is partially distorted as a vehicle approaches it. The whole local magnetic field is warped whenever the vehicle is between the final and middle part of the magnetic field produced by the detector. After that, a controller can receive this data.
M5	Global System for Mobile Communication (GSM)	In this method, an embedded controller creates a data pattern to provide a microcontroller's input. The C programming language is then translated into HEX code and sent to the microcontroller receiver. Then, this data will be sent to GSM through the microcontroller's transmitter. With a SIM's 3G connection enabled, the GSM can activate the messaging function and notify a specialist by message.
M6	Infrared Sensor (IR)	The majority of traffic light systems feature infrared (IR) sensors, which are made up of an IR transmitter and receiver. The IR sensors may be turned on whenever the vehicle moves in front of two sensors. The gathered data may be examined to turn the traffic signal green.

CONCLUSION

In this paper, several intelligent traffic management systems were reviewed. These included utilization of RFID readers and tags, Green Wave Systems, smart phones and wireless communication with Big Data center. Applications, pros and cons of each method were discussed and summarized briefly in Tables 1 and 2. The technique of IoT has been used in order to gather data which related to traffic congestion more quickly and more accurately. Furthermore, mobile application was discussed as a "User Interface" to detect traffic congestion in different places and provide users with alternate routes. The goal of these techniques is to provide the drivers of vehicles to know more information about traffic and road conditions. Moreover, the priority for emergency vehicles can be assigned through Intelligent Traffic Systems.

REFERENCES

[1] Chong, H. F., & Ng, D. W. K. (2016, December). Development of IoT device for traffic management system. In Research and Development (SCOReD), 2016 IEEE Student Conference on (pp. 1- 6). IEEE.

[2] Saad, A. A., El Zouka, H. A., & Al-Soufi, S. A. (2016, March). Secure and Intelligent Road Traffic Management System Based on RFID Technology. In Computer Applications & Research (WSCAR), 2016 World Symposium on (pp. 41-46). IEEE.

[3] BBC, "BBC - Nottingham - History - The man who gave us traffic lights, " 2009.

[4] Thatcher, Linda, "Lester F. Wire Invents the Traffic Light - Photos and Stories — FamilySearch. org, " 2013. [Online] Available: https://familysearch.org/photos/artifacts/2128625.

[5] "Communications standards news". IEEE Communications Magazine

[6] Amani A. Saad, Heshem A. El Zouka, Sadek A. Al-Souf. "Secure and Intelligent Road Traffic Management System Based on RFID Technology". World Symposium on Computer Applications & Research 2016.

[7] Mittal, A. K., & Bhandari, D. (2013, February). A novel approach to implement green wave system and detection of stolen vehicles. In Advance Computing Conference (IACC), 2013 IEEE 3rd International (pp. 1055-1059). IEEE.

[8] Geetha. E, V. Viswanadha, and Kavitha. G. "Design of an Intelligent Auto Traffic Signal Controller with Emergency Override". International Journal of Engineering Science and Innovative Technology (IJESIT), July 2014.

[9] Wang, R., Zhang, L., Sun, R., Gong, J., & Cui, L. (2011). EasiTia: A pervasive traffic information acquisition system based on wireless sensor networks. IEEE Transactions on Intelligent Transportation Systems, 12(2), 615-621.

[10] Karric Kwong, Robert Kavaler, Ram Rajagopal, and Pravin Varaiya "Real-Time Measurement of Link Vehicle Count and Travel Time in a Road Network" IEEE transactions on intelligent transportation system, December 2010.

[11] Marcin Bugdol, Zuzanna Segiet and Michał Krecichwost. "Intelligent transportation systems, vehicle detection, anisotropic magneto resistive sensors" IEEE journals, 2014

[12] Händel, P., Ohlsson, J., Ohlsson, M., Skog, I., & Nygren, E. (2014). Smartphone-based measurement systems for road vehicle traffic monitoring and usage-based insurance. IEEE Systems Journal, 8(4), 1238-1248.

[13] Stefan Badura, Anton Lieskovsky "Intelligent Traffic System: Cooperation of MANET and Image Processing, " Integrated Intelligent Computing (ICIIC), 2010 International Conference

[14] Salama, A. S, Saleh, B. K, Eassa, M. M, "Intelligent cross road traffic management system (ICRTMS)," Computer Technology and Development (ICCTD)". IEEE International Conference 2010

[15] Peng Xiaohong, Mo Zhi, Liao Riyao, "Traffic Signal Control for Urban Trunk Road Based on Wireless Sensor Network and Intelligent Algorithm, " International Journal on Smart Sensing and Intelligent Systems, 2013

[16] Khalil M Yousef, Jamal N Al-karaki1, and Alim Shatnawi. "Intelligent Traffic Light Flow Control System Using Wireless Sensors Networks" Journal of information science and engineering, 2010

[17] Pratyush Parida, Sudeep Kumar Dhurua, P. Santhi Priya. "International Journal of Emerging Technology and Advanced Engineering". International Journal of Emerging Technology and Advanced Engineering, October 2014.

[18] Ghazal, B., ElKhatib, K., Chahine, K., & Kherfan, M. (2016, April). Smart traffic light control system. In Electrical, Electronics, Computer Engineering and their Applications (EECEA), 2016 Third International Conference on (pp. 140-145). IEEE.

[19] W. Tiedong and H. Jingjing, "Applying floating car data in traffic monitoring, " 2014 IEEE International Conference on Control Science and Systems Engineering, Yantai, 2014, pp. 96-99.

[20] Intelligent Transportation System (ITS). https://en.wikipedia.org/wiki/Intelligent_transportation_system

[21] Kanungo, A., Sharma, A., & Singla, C. (2014, March). Smart traffic lights switching and

traffic density calculation using video processing. In Engineering and computational sciences (RAECS), 2014 recent advances in (pp. 1-6). IEEE.

[22] Matlab Image Processing and Video Processing Toolbox http://www.mathworks.in/products/image.

[23] Rawat, R., Rajawat, A. S., Mahor, V., Shaw, R. N., & Ghosh, A. (2021). Surveillance robot in cyber intelligence for vulnerability detection. In Machine Learning for Robotics Applications (pp. 107-123). Springer, Singapore.

[24] Rawat, R., Rajawat, A. S., Mahor, V., Shaw, R. N., & Ghosh, A. (2021). Surveillance robot in cyber intelligence for vulnerability detection. In Machine Learning for Robotics Applications (pp. 107-123). Springer, Singapore.

[25] Mahor, V., Rawat, R., Telang, S., Garg, B., Mukhopadhyay, D., & Palimkar, P. (2021, September). Machine Learning based Detection of Cyber Crime Hub Analysis using Twitter Data. In 2021 IEEE 4th International Conference on Computing, Power and Communication Technologies (GUCON) (pp. 1-5). IEEE.

[26] Rawat, R., Mahor, V., Garg, B., Chouhan, M., Pachlasiya, K., & Telang, S. (2022). Modeling of cyber threat analysis and vulnerability in IoT-based healthcare systems during COVID. In Lessons from COVID-19 (pp. 405-425). Academic Press.

[27] Jianwei, L., Hongli, L., Chinmay, C., Keping, Y., Xun, S., & Ziji, M. (2019). Cascade learning embedded vision inspection of rail fastener by using a fault detection IoT vehicle. IEEE Internet of Things Journal, 1, 1.

[28] Kaur, H., & Malhotra, J. (2018). A review of smart parking system based on internet of things. International Journal of Intelligent Systems and Applications in Engineering, 6(4), 248–250.

[29] Mohamad, Z. Z., Yang, F. C., Ramendran, S. C., Rehman, M., Nee, A. Y. H., & Yin, Y. C. (2020). Embedding eco-friendly and smart technology features in affordable housing for community happiness in Malaysia. GeoJournal, 1, 1–15.

[30] Singh, R., Sharma, R., Akram, S. V., Gehlot, A., Buddhi, D., Malik, P. K., & Arya, R. (2021). Highway 4. 0: Digitalization of highways for vulnerable road safety development with intelligent IoT sensors and machine learning. Safety Science, 143, 105407.