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Smart Traffic Control and Congestion Management Systems: A Review

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Abstract:- Traffic congestion has become a vital enigma in most cities across the world. Longer trip times, air pollution, frustration in drivers, noise pollution, road accidents, delay in emergency services, etc. are some major problems people are facing as a result of traffic congestion. Old-fashioned traffic lights set up in cities are unable to meet the needs of advanced cities because these traffic lights have an exact predetermined time interval from a red phase to a green phase. Such systems do not take vehicular density into consideration. Several works based on sensors, image processing, IoT, RFID, etc. have been explored a great deal to automate the traffic lights according to the density of the vehicles on the road. The work presented here highlights the state of art of all the new and emerging methods of smart traffic management and the associated challenges. Overall, the paper reviews and summarizes the various methods of traffic management systems.

Keywords:- *Traffic Control; Image Processing; IR Sensor; Spontaneous Synchronization; VANET; IoT; Inductive loop.*

I. INTRODUCTION

The traffic management has been an interesting and important problem throughout the world ever since the advent of motor vehicles. The first motor vehicle was introduced on the Indian streets in the year 1897. At that time automobiles were confined exclusively to the rich people. But motorized industries were also set up in India due to the industrial revolution, reducing the overall cost of vehicles. The number of cars purchased by Indian families increased by 70 percent from the beginning of the 21st century [1]. In most urban cities of the world, the constant increase in the number of road vehicles has increased traffic congestion. Traffic congestion has become a critical enigma as it not only affects travel time of the commuters but also contributes to air pollution, noise pollution, road mishaps, frustration in commuters etc. Building new roads can only provide limited help as most urban cities lack the free space needed to build new roods. Moreover, new roads will only support more vehicles as the rate at which people buy vehicles surpasses that of building new roads. This is consistent with the "basic law of road congestion" suggested by Downs [2], which states that the increase in road supply necessarily increases vehicular traffic.

India is world's second most populated country with approximately 1.36 billion people [3]. Around 33% of its population resides in urban areas with urban population increasing at a tremendous rate. The traffic density has also increased as people purchase more cars and bikes for their convenience. In India, a person's average time spent on a traffic signal is much higher in comparison to majority of developed countries. Traffic signals are either manually monitored or using timers in most places. Manual traffic surveillance requires the traffic police, which corresponds to the inadequate application of manpower. Predetermined timers are used in many places in India. The problems faced by commuters because of predetermined timers are that these timers are based on average traffic density and vehicles have to stop before a red signal even if the traffic in the other lanes is nil. This wastes lot of travel time of the commuters. Many a times, people skip traffic signals due to lack of patience, resulting in accidents. Traffic control helps in traffic flow regulation, congestion management and even reduction in the emissions. Apart from manual controlling of traffic and fixed signal cycle control, actuated traffic signal control employing induction loop detectors, IR sensors are also being used at some places. The effectiveness of the road traffic network can be enhanced using self-adaptive control instead of timing control and actuated control [4]. The growth of wireless communication technologies has created an opportunity for interaction between vehicle-to- vehicle (V2V) and vehicle to infrastructure (V2I) systems. The Various traffic management schemes to automate and optimize traffic flow have been reviewed in this paper. Methods like Image Processing, Inductive Loop Detector, VANET, spontaneous synchronization, IR Sensors, IoT, etc. have been discussed. Overall, the paper highlights state of art in the area of traffic management system and associated practices commonly used at global level.

This paper has been divided into three sections. Section II summarizes the various methods of traffic management systems and their associated strengths and challenges. The paper is concluded in Section III.

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II. TRAFFIC CONGESTION CONTROL METHODOLOGIES

In this section, various schemes which are popularly followed or are studied for effective handling and management of on-road traffic globally, are elaborated.

A. Manual Controlling Traffic Management Scheme

In this scheme, traffic police are required to control the traffic at intersections. To control the traffic, traffic police carry sign board, sign light and a whistle. They have a peculiar uniform so as to have the attention of the commuters. As shown in Fig.1, the traffic policeman stands at the middle of the intersections and monitors traffic flow.

The traffic police are able to recognize emergency cases and they give priority to the lanes accordingly. This technique is most effective as it involves human intelligence. However, the experience and competence of the police ascertain the effectiveness of the system. The main defect of the system is that it requires huge amount of manpower specially trained for this specialized task.

Fig.1:- Traffic Police at Road Intersections

B. Automatic Traffic Management Scheme

The traffic on the roads of most of the urban cities of the world is controlled by traffic lights set up at the road intersections. The traffic signal control was first introduced in the year 1913 in Cleveland, Ohio, U.S.A. The traffic signal includes three colors, red for stop, amber for wait and green for go. Static traffic lights are the most commonly used method to control the traffic. The synchronization and switching sequence of the fixed signal cycle traffic lights are predetermined irrespective of different traffic conditions present on different lanes. They do not work with real-time traffic data. This means that they do not take account of the unequal and constantly changing nature of traffic conditions. It does not matter if the route has less vehicles or more vehicles, green time and red time do not change accordingly. The cycle time and the green light allocation pattern remain the same for all paths. The first efforts in determining optimal signal timings focused on finding the best stage sequence and stage duration. Average delay was the usual objective function, requiring delay formulae that take into account the variability of traffic flows. Webster (1958) developed such an expression which provides relation between delay and variable traffic flow [5]. The absence of intelligent tactics in these systems does very little to enhance the traffic performance.

C. Inductive Loop Detector Method

The inductive loop detector was introduced in the early 1960s and has become the most utilized sensor in traffic management system **[6]**. Inductive loop detectors can detect vehicles approaching a particular traffic light signal. An electrically conducting loop which is insulated is put into the pavement. The main components of an inductive loop detector include:

- Insulated loop wire
- Lead-in cable
- Electronic unit

Fig. 2, gives the block diagram description of Inductive loop Detector Scheme. Electrical energy in the form of alternating current is applied into the loop by the electronic unit at frequencies between 10 kHz to 200 kHz depending on the model. When any vehicle stops within the loop or passes over the loop, the inductance of the loop decreases. The electronic unit recognizes this event as a decrease in frequency and sends a pulse to the controller indicating the passage or presence of a vehicle. In **[7]**, a system employing two loops in each lane to estimate traffic density has been proposed. Radio transmitter-receiver is used to detect emergency vehicles and congestion free route has been provided to them. The inductive loop detector scheme offers following advantages:

- This technology is quite cheap. Almost every traffic control system around the world uses this technique.
- Performs well in both dense and sparse vehicle traffic.

However, this approach suffers from various disadvantages as follows:

- Loops get damaged by penetration of water or by road maintenance activities.
- Radio interference might occur between loops in close proximity with each other.
- It is unsuited for use on metal floor of bridges.

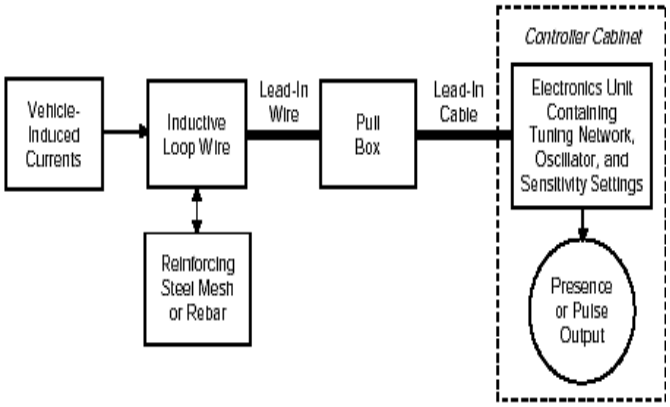

Fig. 2:- Inductive Loop Detector System

D. Traffic Management Using Infrared (IR) Sensors

IR Sensors are used for detecting obstacles (i.e. vehicles), based on the IR light transmitter and receiver and then making the traffic signal automatic based on the density **[8]**. These IR sensors are of great help in finding the vehicle density in real time. It recognizes vehicles in all roads that are kept in particular ranges in order to detect the number of vehicles on the route and allows the signaling to be automated. The ordinary IR sensor can detect objects in ranges up to 10-500 m. This makes it possible for the IR sensors to be set to specific distances within the range specified by the sensor and to detect obstacles like vehicles and to transmit the recorded values to the database. Traffic signals are mainly automated based on the recorded sensor values, and so the traffic present in a particular area may also be reduced and monitored.

The work in **[9]** presents a model with two IR sensors set at specific distance apart. When any car passes through the first sensor, it automatically increases the count and when the same vehicle passes the other sensor, the count gets reduced. The presence of traffic jam is found out if the count increased by the first sensor does not get decreased by the second sensor. The counting done by the IR sensors is not hundred percent accurate and therefore needs to improve.

E. Traffic Management Using Photoelectric Sensors

In [10], an intelligent cross road traffic management system based on photoelectric sensors has been proposed. The suitable distance for these sensors is determined so as to monitor vehicles going towards particular traffic signal and report this information to the intelligent software put up in the traffic control room, which is used to control traffic lights. The software uses an algorithm of giving weightage to different lanes based on traffic density. For more congested route, the green time allotted to the route intersections is more as compared to the less congested route. An active RFID based technology is employed to give attention to the emergency vehicles.

The above system has the following advantages:

- Reduces waiting time at intersections and thus controls congestion and maintains smooth traffic flow.
- It gets rid of human interference in controlling traffic lights.
- It solves the problem of emergency vehicles effectively.

The above system is not fully efficient and it needs improvement.

F. Traffic Management Using Image Processing

Image processing was applied to the road traffic system for the first time in 1973 **[11]**. Image processing is a modern method to control and monitor vehicular traffic congestion. In comparison with methodologies employing sensors like loop detector, infrared detector etc., it is more reliable and efficient. In the work presented in **[12]**, Traffic Flow Measurement System (TMS-II) has been described which is based on vehicle cluster concept. It is a real-time system which accurately determines vehicle locations, vehicle speed, congestion etc. with the help of image processing. TMS-II includes a TV camera, a video processor and a micro processing system. The experimental results show that the accuracy of detecting vehicle cluster was rated at 97%.

In **[13]**, a traffic control system implying image processing has been proposed which changes the signal timing according to traffic density and traffic count. The controlling of traffic lights has been accomplished with the help of microcontroller board (Arduino UNO). The proposed system is cost efficient as it does not involve installation of complicated and costly machines. But the traffic estimation was only 70-80% accurate. In **[14]**, a traffic surveillance system has been proposed which is based on vehicle counting with the help of blob detection approach. This system provides real-time information by analyzing the blob of the vehicles. A system for emergency vehicle detection using image processing has also been implemented. The work reported in **[15]** is based on computer vision techniques to analyze and monitor traffic flow. Image processing operations like image filtering, correction and segmentation has been employed in this system. This system is capable of measuring speed of vehicles, vehicle tracking, jam detection etc. In **[16]**, traffic light is controlled with the help of image processing. The system uses a camera to capture image and the images are sequentially matched with the reference image which is of an empty road. Prewitt edge detection operator has been used to carry out this operation. It reduces traffic congestion and escapes the wastage of green signal on an empty road. But it still needs improvement to attain hundred percent accuracy. The scheme of **[12]** is presented in figure (3).

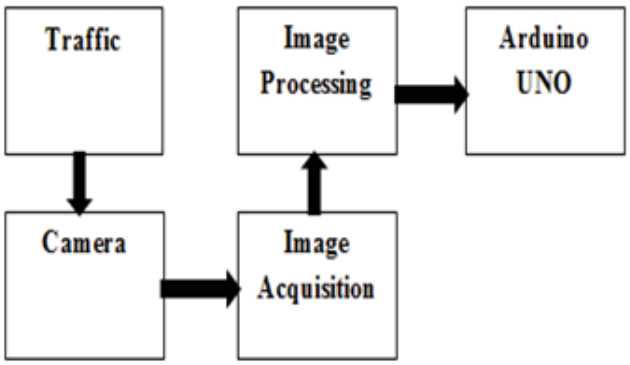

Fig 3:- Block Diagram of the System Proposed in [13].

G. Traffic Management Using VANET

In the last decades, Intelligent Transport System (ITS) has become the backbone of today's transportation system. Vehicular Ad Hoc Network (VANET), which allows inter-vehicular communication as well as communication between vehicles and fixed infrastructure as shown in Fig. 4. In **[17]**, adaptive traffic signal control based on vehicle to vehicle communication has been designed and implemented. With the help of this system, the waiting time of the vehicles at intersections gets reduced and vehicular queuing also decreases reasonably. The work in **[18]**

introduces a system which uses VANET to support Intelligent Traffic System. Inter vehicular communication and communication between vehicles and road side units (RSUs) are features of this system. This paper also presents a scheme forming a smart city framework that conveys information about traffic conditions to the drivers so that they can take correct decisions and choose the less congested road.

The system architecture has the following modules **[18]**:

- Warning message module: This modules function is to determine whether any accidents have occurred and report it to the driver about the same. The information this module gathers is directed to the subsequent module, i.e. Module measuring traffic density.
- Density of traffic calculation module: This module computes the density of traffic on individual road.
- Decision-making module: The above two modules gather their information and send it to the decision-making module where a decision is taken to provide automobiles with a congestion-free route.

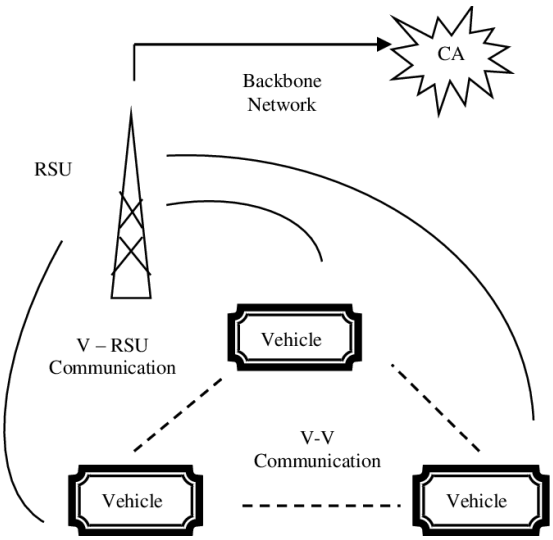

Fig 4:- Architecture Diagram of VANET Based Traffic Management System

H. Traffic Management using Internet of Things (IoT)

The term "Internet of Things" was coined in 1999 by Kevin Ashton. IoT can be understood as a system involving electronic devices equipped with sensors and internet connectivity that can communicate with each other over the internet. IoT applied to road traffic is made up of three layers: application, network and acquisition **[19-21]**.

The application layer is responsible for the collection, storage and processing of traffic data. Presentation of the traffic IoT interface to users and analysis of the information received from the acquisition layer are also the functions of application layer. The network layer also called as transport layer consists of Internet, Wi-Fi, WiMAX, GPRS etc. The function of the network layer is to transmit data securely and process the information received from the acquisition layer. Acquisition layer includes various kinds of sensors like RFID, EPC, WSN, cameras etc. Its main function includes collection, monitoring of objects and transfer of data to the network layer in real time from IoT sensors. In **[20]**, Intelligent Traffic Monitoring System is implemented. Vehicle identification is done by using EPC code and using RFID reader to read these codes with the help of RF electromagnetic wave. Vehicular position is obtained from GPS technology. In **[22]**, with the help of smart phones, traffic flow is dynamically controlled by onsite traffic officers. In **[23]**, traffic density is the input to the system which is obtained from cameras with the help of Digital Image Processing technique. To minimize traffic congestion, a suitable algorithm is used for future traffic density prediction. RFID tags are also installed in emergency vehicles to prioritize them for their uninterrupted services.

A mobile application is connected to a remote server which gives information regarding emergency situations to the nearby help centers. In **[24]**, traffic control system based on IoT is developed. The system takes into consideration the real time traffic density measurement. This is accomplished by using a real time video and image processing techniques. Using cameras, the images are taken and stored in the server where it is compared with the real time image taken by the camera to measure the density. In **[25]**, Intelligent Traffic System is implemented using RSUs which monitors friction, automobiles with temperature and humidity sensors and a database for transferring data via various channels. The advantages of using IoT in traffic system includes low cost, high reliability, weather proof, easy upgradability etc.

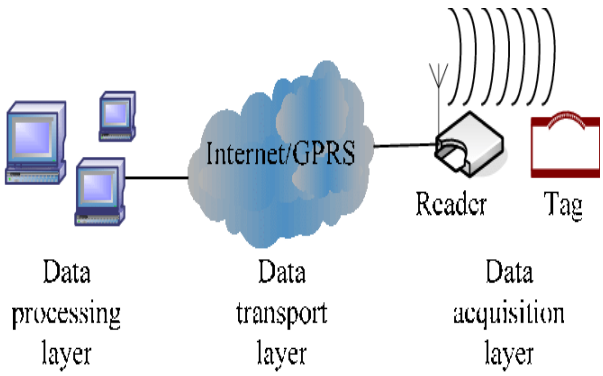

Fig 5:- Architecture of Internet of Things

I. Spontaneous Synchronization Method (SSM)

A distributed traffic control method for urban transport network control is presented in **[26]**. Spontaneous synchronization inspires this approach of traffic management. Spontaneous synchronization can be defined as a natural process in which a group of similar entities involuntarily starts imitating each other through mutual interactions until all of them attain simultaneity. Complex processes get easier with the help of synchronization mechanism. Thus, at intersections, every traffic signal system is modelled as a phase-oscillator and by synchronizing these oscillators, the desired global

synchronization can be accomplished. The control process consists of the following steps:

- First, every oscillator (intersection) runs on its own frequency independently.
- As time passes by, the most similar oscillators (intersections with almost same cycle) will achieve synchronization first.
- More and more oscillators are then synchronized.
- Finally, the entire network is synced or divided into several stable, synchronized subnetworks.

The best thing about this method is that it is independent of any architecture and predefined rules. Adaptive traffic control can be achieved with this method when adjacent intersections have similar traffic state and signal timing. However, synchronization time depends on the extent of coupling and also on the population of oscillators. As the number of oscillators increases, synchronization time also increases.

III. CONCLUSION

This paper provides a review of methods that have been used for traffic management. Traffic jams have become serious problems for commuters. Automated traffic management system based on traffic density is the need of the hour. The characteristics of Indian roads and traffic make the problem interesting to solve. There is scope for evaluating existing ideas in different and challenging traffic scenarios and innovate new solutions. One such solution is traffic control based on spontaneous synchronization. It does not rely on any network architecture and predefined rules and is ideal for traffic management. This method has potential to be very effective method of traffic management. Overall, the current paper has summarized the strengths and challenges of different schemes of Traffic Management Systems commonly highlighted in literature.

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