Smart Traffic Monitoring and Control Architecture and Design

Airull Azizi Awang Lah[1], L. A.Latiff[2], Rudzidatul Akmam Dziyauddin[3], Hazilah Mad Kaidi[4], Norulhusna Ahmad[5]
Razak School of Engineering & Advanced Technology
Universiti Teknologi Malaysia
Kuala Lumpur, Malaysia
[1]aazizi9@graduate.utm.my, [2]liza.kl@utm.my, [3]rudzidatul.kl@utm.my, [4]hazilah.kl@utm.my, [5]norulhusna.kl@utm.my

Abstract— **The road traffic volume is the main criteria in the road planning and traffic management. Previous studies have discussed on the smart traffic monitoring, and little attention has been paid to the solution of smart traffic control. The objective of this paper is to propose a smart traffic monitoring and control architecture and also the respective algorithm using sensors. This paper assumed that sensors are strategically placed along the road to detect traffic volume. These information will then be transmitted via Low Power Wide Area Network (LoPWAN) to a dedicated control centre. There will be server in the control centre that controls the traffic lights scheduling at the junctions. The proposed solution can be further developed and tested using hardware.**

Keywords— ***smart traffic, earth magnetic, IoT, LoPWAN, traffic monitoring.***

I. Introduction

Traffic congestion is becoming major issues in cities and metropolitan areas in most countries. Various factors have been identified that contribute to traffic congestion, such as bad road conditions, inefficient traffic flow controls, increased number of vehicles on the roads and even at times ill-mannered practices of road users. Traffic congestion poses serious challenges towards the city infrastructure facilities and also affect the socio economic lives of the people due to time wasted while waiting in traffic. High Priority Vehicle (HPV) are also affected which results in time delay for these vehicles to reach their destinations especially in a life-threatening condition.

The current traffic lights timing operates by using the conventional approach where time for each road segment is fixed. Each road segment has its own specific different road and path that meets at a junction. The biggest concern with traffic congestions is the delayed of HPV's whereby the driver will encounter difficulties to reach its destination in fastest time especially around the cities. A fixed timing of traffic lights might cause certain delays for the HPV to arrive on time due to it has no special priority. To solve this problem, a centralised traffic monitoring and management is required based on varying the timing of traffic lights which commensurate the seriousness of the congestion. This requires infrastructure that allows information of congestion to be recorded and updated. The advancement of technology of connected devices and systems can improve the updating of information surrounding human in their daily life.

Internet of Things (IoT) is a new paradigm, which involves intercommunication between different devices without human intervention, such as automated collection, processing and analysis of large amounts of data, all generated by the sensors. The IoT makes possible high-accuracy probabilistic behavioral environmental models development. These models allow increasing the levels of comfort and security in everyday life due to continuous monitoring of the data obtained from sensors in real time.

This paper presents a conceptual work of smart traffic light integrated with IoT. The main aim of this infrastructure is an effective and optimal road traffic management that can make possible development of a new generation information infrastructure in the future. This work is also beneficial in developing the smart cities.

This paper presents a background of the new system in Section 2, followed by a discussion on possible solutions in Section 3. Section 4 presents the proposed work in detail. Section 5 discusses on the proposed monitoring algorithm, and followed by the conclusion in Section 6.

II. Background

A congestion on any roads will slow down the vehicles speed, increase travelling time and expand the vehicles lining. Congestion occurred when total number of vehicles on the street exceed the streets limit. This is a noteworthy issues especially in the metropolitan urban communities [1]. The traffic congestion can be translated into loss of productivity follow by wasted fuel and environmental damage. Indirect hidden cost will also decline in public health due to stress from traffic congestion. The main cause of congestion is lack of public transport option, increase car ownership, lack of comprehensive public transport option and long waiting times [2]. Collected data showed that an increase number of vehicle crashes occur frequently in the areas around congested road because the drivers tend to drive faster before or after encountering a traffic jam [3]. Lack of awareness from the driver towards the conditions of the traffic ahead was the main cause of crashes because the driver was unable to hit the brake on time because of the traffic jam ahead.

It is found that Malaysian economy is growing rapidly at the present time which leads to increase the number of vehicles in an escalating manner. Since 1970 the urbanization pace in Malaysia took a swifter pace. The rapid growth in urbanization

978-1-5386-2126-4/17/$31.00 ©2017 IEEE

and motorization mainly due to the expanding economy. The urban economy and development is well-dependent and influenced by transportation. A growth in economy and development means an expansion in the transportation sector as well. Most people prefer to own and use cars because of the degree of freedom, accessibility, passion for car and driving, comfort and negative perception on public transport [4].

There are a few technologies available in the market that combines the traffic light with IoT. Nevertheless, the overall system still relies much on human intervention. A few types of sensors were installed at the traffic light use video images, ultrasonic, acoustic, magnetic and inductive loops mechanisms. All these sensors gather data and send back to the processing centre to be processed manually, and the output to control the traffic light timing is done via human intervention.

III. Related works

Many researchers have proposed different theories and technologies to solve traffic congestion. Researchers in [5] introduced a cognitive traffic management system (CTMS) as a replacement to existing traffic lights to exclude mistakes caused by human factor. Some papers [6] and [7] discussed a genetic algorithm called shortest path finding algorithm. In [8], infrared sensors and a system based on Peripheral Interface Controller (PIC) microcontroller were used to evaluate the traffic density and produce a dynamic timing slots with different levels.

Bio-inspired algorithm used in [9] reduce the average vehicles waiting time at the intersection by control the traffic signal intersection. This was achieved by implementing an intelligent-based system that simulates the insects (ants) life. Researchers of [10] investigate the parallelism benefit of this complex problem and proposed to use the differential evolution as a solution for traffic light scheduling problem. A system to detect traffic congestion and incidents using real-time GPS data and drivers smartphone was presented in [11]. The researchers able to proof that the system able to identify different levels of congestion from different road.

Some researchers have focused on Intelligent Transport System (ITS) which employs the use of artificial intelligence techniques combined with the latest development of data sensing and communication technologies. ITS have gained some popularity among researchers in providing traffic information and informing drivers to select a better route. [12]-[14] explain in detail the applications of ITS to control traffic congestion. Another method of traffic control is using Wireless Sensor Networks (WSN). Researcher in [15] utilize a WSN integrated with an algorithm to provide real-time traffic surveillance. WSN consists of various types of sensors from video image, acoustic, magnetic, ultrasonic, inductive-loops to name a few. The ultrasonic sensor is best used in parking environment. It has high accuracy, low-cost and easy installation. However, it is sensitive to extreme air turbulence and temperature fluctuations [16] and makes it not suitable to be deployed in congested area with high volume of traffic.

The other option of sensors is using a magnetic sensor. The earth magnetic field can be distorted by any metallic object, such as vehicle [17]. The researcher uses a sensing unit in a monomer magnetic sensor arranged in a perpendicular location to detect a passing ferromagnetic objects. They introduced a linear algorithm based on a magnetic dipole to identify the moving direction of the ferromagnetic object. Magnetic anomaly detection is a good method for detecting ferromagnetic objects.

A group of researcher had explored the work on moving target detection using a static three-axis referenced magnetometer [18]. [19] explained in details in mechanism to measure distortion by vehicles using magnetic sensor. Magnetic sensor based in magneto-resistors are very sensitive and responsive. It can detect changes in earth magnetic field due to presence of any metallic objects such as vehicles. However, continuous operation would drain the power at faster rate, hence the researcher integrate an event-based software for a low power sensor node. The three works [17]–[19] focused on the object detection using magnetic detection. [17] and [18] only focused on identifying the moving direction of ferromagnetic objects, and [19] explored the use of low power magnetic sensors. None of them discusses on the platform or mechanism to transmit the data from the sensors to the centralized controller.

Other than sensor portion to collect data, data transmission from the sensor to centralized controller and vice versa plays an important role too. The sensor will be installed in a few strategic locations along the roads, and there are several obstacles that has been identified and become part of the criteria when selecting the suitable transmission medium [20]. The obstacles are:

i. Line Of Sight (LOS) requirements.
ii. High reliability.
iii. Accuracy and synchronized time.

[21] used Vehicular Ad hoc Network (VANET) and Radio Identification (RFID) as the transmission medium. However, these solutions work well if all vehicles on the road are equipped with the required hardware. In [22], General Packet Radio Service (GPRS) module was selected to carry data from a passive RFID that used as the WSN to the central server. [23] proposed passive RFID tags with high frequency tags and Global Positioning System (GPS) to manage the road traffic system. The work in [24] focused on using single magnetic sensor for traffic measurement and vehicle classification. Although the paper detailed out the mechanism and algorithm used for traffic measurement and vehicle classification, there is still a gap in terms of smart traffic monitoring and control. Another work [25] explained in details the use of magnetic sensor for traffic surveillance. The magnetic sensors are connected to the centralized server via General Packet Radio Access (GPRS) connections. The analysis on vehicle detection is comprehensive, however, the work is also lacking for the solution of smart traffic control. Therefore, the present study sheds new light on smart traffic monitoring and also traffic control using magnetic sensor over Low Power Wide Area Networks (LoPWANs).

IV. PROPOSED SMART TRAFFIC MONITORING AND CONTROL ARCHITECTURE

Based on previous works, we propose using magnetic sensors and Low Power Wide Area Network (LoPWAN) as a solution for smart traffic monitoring. Magnetic sensors based on magneto-resistors were selected as sensors because it is highly sensitive to magnetic anomaly in the earth magnetic field due to vehicle presence. Besides it is widely known that magnetic field is independent of weather condition and this serve as extra merit compared to other types of sensor networks. With the data captured from the sensor, it can be translated into traffic condition and then transmitted to the centralized controller that control and manage the traffic lights operation. The centralized controller will be a brain that controls the smart traffic by running a unique algorithm. The proposed algorithm introduced a dynamic threshold for the traffic volume instead of fixed threshold to achieve an effective traffic monitoring. To cover a large area, all magnetic sensors will be connected over wireless networks since wired sensor networks are impractical because of high deployment and maintenance cost.

The magnetic sensor will detect the vehicle volume in a defined area. This system consists of four main parts;

i. Wireless sensor network (WSN) using magnetic sensor to obtained traffic information.
ii. Data transmission network to transmit data captured from WSN to and from the centralized server.
iii. Centralized server to process the traffic information and control the traffic lights.
iv. Centralized control of traffic lights timing.

Fig. 1 shows the overall smart traffic monitoring system architecture.

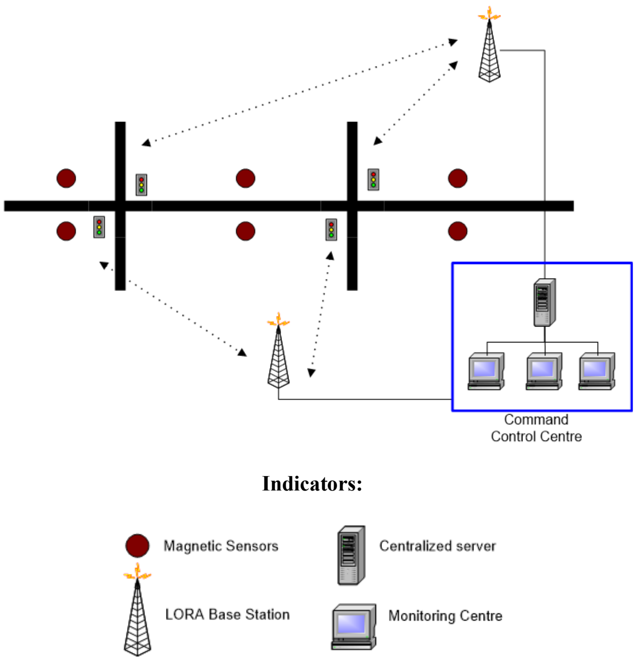

Fig. 1: Smart traffic monitoring system architecture

The main components in the proposed smart traffic monitoring system can be explained as follows

A. Magnetic Sensor.

All body of vehicles are made of metal which have a significant amount of ferrous metals that will create disturbance to the earth's magnetic field. This disturbance can be detected by magnetic sensor [19]. The waveform appeared from the magnetic signal induced by a vehicle is correlated to the vehicle's configuration and size. All information will be transmitted to the nearest base station. This information will be time-stamped using the master node in the centralized server as a clock source and provide time synchronization for all nodes.

B. Data Transmission.

Low Power Wide Area Network (LoPWAN) has been chosen as a transport technology to transmit data captured from magnetic sensors to the centralized server and from centralized server to centralized traffic lights. Researchers in [26] have evaluated the LoRA performance and the advantages are:

- Wide coverage range, 5 km in urban area and 15 km in sub-urban areas.
- Low power consumptions.
- Simple architecture which is easier for deployment.
- Ability to operate efficiently in non-LOS environment. [27] conducted a field test that evaluates the performance of LoRA in both LOS and non-LOS environments.

The same transmission method will be used as a medium of communication between centralized server and traffic lights.

C. Centralized Server.

It will be installed with system application that will control the whole system operation. Upon receiving a data from magnetic sensor, the system application will analyze the traffic pattern using our proposed algorithm which will be explained in Section 5. The system application will also control the traffic light operations to ensure it gives more priority to critical lanes or lanes that have higher traffic volumes.

D. Centralized Traffic Lights.

It will be equipped with a LoRA receiver and transmitter to receive/transmit instruction from/to the centralized server. In every interval of 15 minutes, the traffic light will send a small packet size of a few bytes per second (bps) to the centralized server and the server will acknowledge by sending a reply. This is a mechanism to determine if all the traffic lights in the system is working well.

V. SMART TRAFFIC MONITORING AND TRAFFIC ALGORITHM

This is the essence of this paper. The vehicle detection mechanism using magnetic sensor integrated with an algorithm for smart traffic control. Fig. 2 presents the flowchart of the proposed system. In step 1, whenever a vehicle passes through the area where the magnetic sensor are located, there will be a change in the earth magnetic field readings.

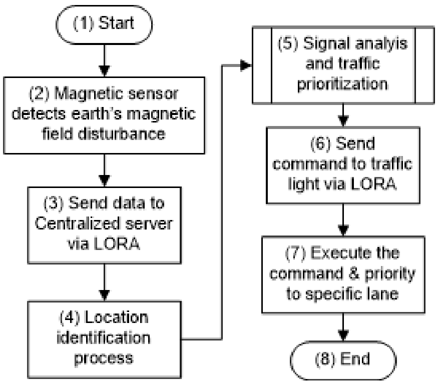

Fig. 2: Flowchart system operation.

The magnetic sensor detects earth's magnetic anomaly, as in step 2. The magnetic sensors will be equipped with a LoRA receiver and transmitter. Each of the LoRA access points will be configured with an IP number for location identification. The changes in magnetic anomaly is translated into voltages and sent to the centralized server via LoRA (step 3). When transmitting the data packets over LoRA, basically the packet structure is depicted as in Fig. 3, which consists of IP header, the magnetic sensor ID and the disturbance in volts.

IP header (from LoRA AP)	Magnetic sensor ID	Magnetic value disturbance (in Volts)

Fig. 3: Packets structure from magnetic sensor to centralized database.

There is a LoRA base station at the centralized server. An algorithm show in Fig. 4 will be used in step 4 to 6 (Fig. 2) to classify the data and perform the signal analysis. Step 4 shows the location identification. This is a stage where the magnetic signals will be classified based from their location. From the data packets, the packet structure will be analyzed and grouped into a similar group station which means they are located on the same road/lane. The IP number from the LoRA access point will be used in the classification process. After segregation is done, it will calculate the voltage which corresponds to the amount of magnetic disturbance. The higher the amount, the higher the traffic volume in the lanes.

The next step is signal processing, as shown in step 5. The signal processing will process the magnetic signal disturbances to identify which road/lane that have a higher traffic volume or critical. Fig. 4 shows the algorithm used in the signal processing.

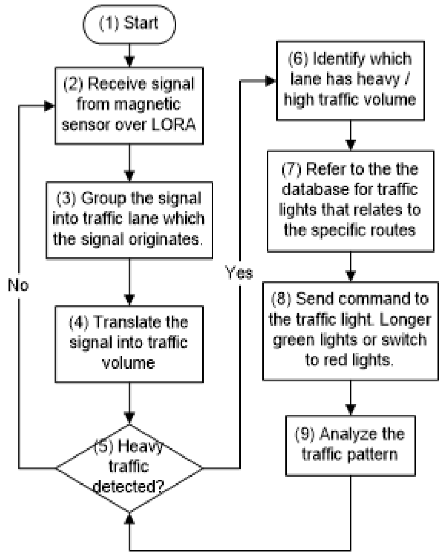

Fig. 4: Algorithm for system application in centralized server.

Referring to Fig. 4, in Step 6, there are several thresholds set to classify traffic volume based on the number of vehicles. A dynamic threshold is proposed instead of fixed threshold to achieve a higher accuracy reading. In dynamic threshold, comparisons in percentage will be made between the traffic to identify which road has the highest traffic volume. If fixed threshold is used, the accuracy will be affected especially in certain time of a day or in a week. Table 1 shows an example of the dynamic threshold to be used.

Table 1: Dynamic threshold.

Lane	Voltage, V	Average Voltage, V_A	% Voltage Differences With Average Voltage
1	3	(3+7+4+5)/4 = 4.75	(36.84)
2	7		47.37
3	4		(15.79)
4	5		5.26

The average voltage is the threshold value set in a certain time and changes in every 15 minutes interval. The highest percentage in voltage differences indicates the lane has a high volume of traffic. Based on Table 1, lane 2 has the highest voltage differences and means it has more vehicles passing through the lane. The voltage differences changes throughout the day and typically will show the exact traffic during that time.

If a fixed threshold is set, the average voltage will not vary throughout the day because there is no information on total number of vehicles that pass through the lane. Hence, the decision to control the traffic lights will be inaccurate.

The centralized system will have full control and integrate all traffic lights in the area. The output from Step 6 will be use in Step 7 to control the traffic light scheduling. As seen in Step 7, the system will identify which traffic lights along the road that needs to adjust and send command to the designated traffic light to give priority to lane 2 or longer green light. It has the ability to switch the traffic light operation sequences to give more priority to specific lane. If the traffic lights in lane 2 turns green, other corresponding traffic lights will be turn to red. The centralized system also has the features to detect malfunction of the traffic lights. The traffic lights will periodically transmit small bytes of packets to the centralized server. If no packets received, it is an indicator that the specific traffic light is not working. A notification will be sent to technician in charge to go to the site and perform troubleshooting.

VI. CONCLUSION

In this paper, we have presented a proposal for Smart Traffic Monitoring system that can be developed to improve traffic efficiency by reducing and controlling the attributes to traffic congestion. Our proposal was based on innovative solution based on the disturbance to the earth magnetic field due to movement of metal object (vehicles) on the road. In our system, the key aim is to enhance the traffic management in order to create a healthier lifestyle by spending less unnecessary time on the road especially during peak hours. Future work is to develop the proposed smart traffic monitoring prototype.

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