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Wireless Magnetometer for Vehicle Count and Monitoring on Thingspeak Dashboard

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Abstract: Manually gather statistical data on the traffic density levels is not efficient in enhancing the traffic control system. Current intrusive traffic surveillance technology was found causing large damage on the road surface and high cost. Thus, a wireless magnetometer sensor capable of implanting in the road with a small uniform area was developed to measure the three-axis magnetic flux changes when a vehicle passes over the sensor. This system consists of an HMC5883L magnetometer, microcontroller, and transceiver RF433MHz. The sensor data will be processed by the microcontroller, transmitted, and received via wireless transmission at 433MHz. Interfaces of wifi module ESP8266 and microcontroller at the receiver node allows network access and upload the received data to the cloud of Thingspeak via TCP protocol. In our project findings, 96% of counting accuracy is archived for real-time testing when the transmitter and receiver's node distance is 1 meter and maintained above 80% when the distance is increased to 5 meters. 1 second to 1.3 seconds of real-time delays is obtained among the transmitter and receiver's node distance from 1 to 5 meters. The magnetic field pattern based on the readings of the x, y, and z-axis was observed. The signal transmission is within a distance of 5 meters between transceivers and a latency of 15 seconds to the Cloud. The number of vehicles in real-time was successfully counted and monitored via Thingspeak's dashboard.

Keywords: Magnetometer Sensor, RF433MHz Transceiver, ESP8266, Thingspeak

1. Introduction

Real-time traffic monitoring is needed in today's high-density traffic flow cities to maintain the transport infrastructure statistics and track the traffic density level to enhance traffic management. These real-time traffic volume statistic enabled transportation agencies to evaluate the effectiveness of reducing traffic congestion strategies over the years. It allows observing the existing traffic behaviours continuously at regular intervals, finding out the location with traffic congestion issue and simulation

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on the city's transport network. The traffic engineer can analyze the traffic flow by taking into account several factors such as adequate street directions to minimize travel times, the influence of traffic lights synchronization and placement in traffic congestion through traffic surveillance. Therefore, a variety of surveillance technology is widely implemented in real-time traffic.

These existing technologies comprised of three different categories, which are intrusive, non-intrusive and off-roadway installation. Intrusive sensors such as weight-in-motion sensors, magnetic detectors and inductive loop detectors are mainly embedded in the road surface via saw-cuts or add holes. For non-intrusive sensors with infrared (IR) and ultrasonic technology, vision or microwave radar is often placed overhead or roadside surface while GPS receivers or remote sensing technologies in off-roadway categories do not require any roadway installation. The detailed description of the three categories of technologies can be found further in [1][2].

However, the technologies mentioned above had drawbacks, making the real-time monitoring system inefficient and reliable. Those intrusive sensors had large sizing and costly while very dependent on the power supply. They need to be maintained regularly, whereas a traffic disruption occurred neither installation phases nor maintenance. The performance of non-intrusive sensors can be affected by weather conditions. Furthermore, off-roadway technologies are high cost and limit the traffic surveillance system's unique distribution and integration. The drawbacks of the existing traffic monitoring system are further explained by J.L.Wilder et al. [3]. They had mentioned that the current method for improving traffic flow management is costly and preliminary labour based as well as through remote monitoring. Apart from this, Somashekhar et al. [4] also mentioned the inductive loop detector’s disadvantages in their report, such that this type of intrusive sensor technology had a high failure rate when implanted the induction-loop wire in poor quality of road surfaces, blocking certain traffic during maintenance phases and cause damage to the surface of the road. IR sensor is not an effective traffic surveillance technology as it can be affected by fog. In [5,6], the induction loop is used for vehicles detection for two categories: wrong lane and wrong-way, which has caused fatal road accidents in the United States of America.

Magnetometer and wireless sensors networks come to the solution for the existing real-time traffic surveillance system. A magnetometer is an instrument that was used to measure the strength and direction of magnetic fields. It can act as a metal detector that is magnetic or ferrous. This element provides an alternative solution for the existing traffic surveillance commercial devices as it is sensitive to the ferrous material, small size, lightweight and cost-effective. It had a longer life span and eliminated the need for a line of sight. [7]. Wireless sensors networks (WSN) are emerging technologies, and they served enormous umber of sensing applications such that the Internet of Things (IoT). WSNs consist of several features like power efficiency, reliability, flexibility and scalable [8]. A sensor node consists of a few crucial components :1) microcontroller 2) memory 3) receiver-transmitter 4) power supply [9]. Integration of magnetometer and WSN enable the real-time traffic monitoring off-labour and cost-effective. According to J.L.Wilder et al. [3], existing WSNs sensors nodes such as TelosB or Mica Z is too costly. Thus, a sensors node with magnetic sensors (HMC5883L) in their Smart-Vehicle Detection System (SVEDECS) mainly focuses on providing real-time traffic flow's statistic and vehicle type and speed tracking.

N. Wahlström, et al. [5] had proposed a two-axis magnetometer sensor for the traffic monitoring where the vehicle's direction is detected. Upon 511 samples is tested, a 99% detection rate was obtained when cars near passed the sensor. The performance had decreased to 89% as the signal-to-noise ratio (SNR) decreased. S.Vancin and E.Erdem [10] had proposed a vehicle direction detection system with magnetic sensor nodes via an adaptive threshold algorithm. This study concluded that the detected adaptive threshold provides more accuracy for several systems: 1) vehicle and speed detection. 2) assignment of direction, which placed in different grounds. A result of 98% (left to right) and 96% (right to the left) of vehicle detection rate is obtained. Vehicle detection and classification method using a magnetic signal based on a single axis of the magnetic sensor is proposed by J.Lan et al. [11]. Three types of vehicles, such as light-wheeled vehicle tracked and heavy tracked, are distinguished through the magnetic waveform's concavity and convexity areas and its concave and convex angles. 90% of classification accuracy is obtained due to only 93 samples is experimented. W. Balid et al. [12] proposed a real-time traffic monitoring system with WSN where the researchers conduct 4 hrs real-time monitoring on the highway with the help of a camera. A magnetic sensor node is placed in two different scenarios :1) roadway surface at the centre of the lane. 2) roadside surface adjacent to the road. 99.90% detection rate is obtained for the roadway setup due to miscounted of two high-speed cars. In contrast, 99.95% detection accuracy for the roadside setup due to the flux magnitude variations is more uniform and contributes to accuracy.

This project had the aim to develop an intrusive traffic surveillance technology that had smaller size, cost-effective, and lightweight, as well as eliminate the weather condition factors which would affect the performance of sensors. The prototype created through this project enabled it to be implanted underground in a small area to not cause road surface damage like the other intrusive technology. Thus, integration of magnetometer and WSN is done where the magnetometer sensor HMC5883L will detects vehicle count and send the data to the RF transceiver at 433MHz. As the number of cars used among Malaysians increased significantly, this intrusive magnetometer sensor project is very useful because it uses the latest technology and applies the Internet of Things (IoT). The data collected from this project through the IoT platform can analyze Malaysia's traffic flow intensity. Traffic control can be customized according to each region's traffic density to ensure a smooth traffic flow.

2. Materials and Methods

2.1 Materials

In hardware development, magnetometer sensor (HMC5883L), Arduino Uno R3, RF433MHZ transceiver and Wi-Fi module (ESP8266) were used. HMC5883L is used to measure the magnetization of ferromagnet and to specify the direction of the magnetic field at a point. Arduino Uno R3 acts as processing unit to process the data received from the input sensor and give command to the output. RF433MHZ transceiver receives serial data and transmits to the receiver and operates at specific frequency of 433MHz. ESP8266 sends the sensor data to Cloud through IoT platform. In software development, two difference software is used which were Arduino IDE and Thingspeak Cloud server. Arduino IDE is a platform for arduino programming while Thingspeak is a IoT platform that use to visualize data sensor in dashboard for analyze data or monitoring purpose.

2.2 Methodology

The wireless magnetometer sensor for vehicle counting is divided into two-part which are the transmitter node and receiver node. The magnetometer sensor (HMC5883L) would sense three-axis magnetic flux for the transmitter node when the ferrous object interfaces the sensor's magnetic field, as shown in Figure 1 (a). Fixed threshold (z-axis) methodology was used for vehicle detection. The calibration of the threshold level needs to be done before installing this device into the underground. The Arduino Uno R3 act as a processing unit will collect the three flux data (x,y,z) from the sensor and compare the fixed threshold and the detected z-field as the number of vehicles will count detected z-field over the fixed threshold value. However, the number of vehicles counted would remain the same as the previous counted value. This microcontroller unit will transfer the detected and process information such as the number of magnetometer sensors, readings of the magnetic field (xyz-field), and the number of vehicles counted via wireless transmission at 433MHz. Next, the data is received through the antenna in the wireless receiver module (RF433MHz) by demodulating the RF signal to recover the information in the receiver node, as shown in Figure 1(b). The Arduino Uno R3 has been programmed to allow a signal at a frequency of 433MHz to be received. This control unit also will be programmed to communicate with the cloud platform, which is Thingspeak over TCP protocol. The control unit implemented this TCP protocol and transmitted the data into cloud computing by passing AT commands serially to the ESP8266 module. At the same time, the data is visualized at the dashboard of Thingspeak. All the raw data recorded with the time stamp can be exported into the .csv file format for further data analysis by the user. The working flow of this project is further explained in the flowchart, as shown in Figure 2.

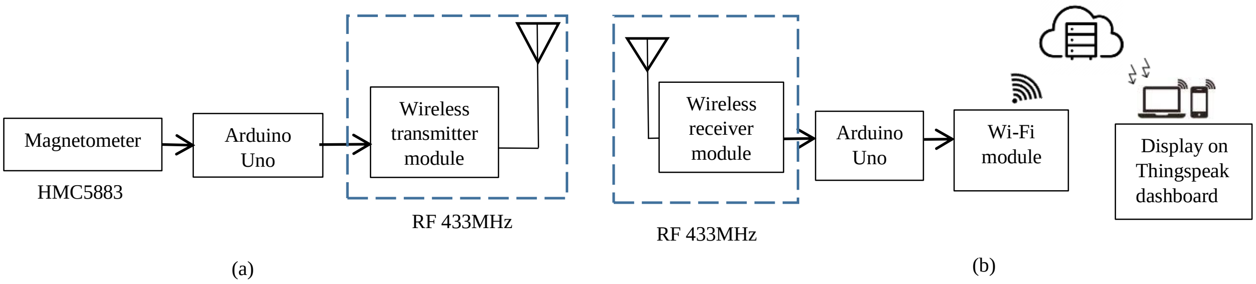

Figure 1: (a) Block diagrams of the transmitter node of the wireless magnetometer for vehicle count and monitoring on Thingspeak dashboard. (b) Block diagrams of the receiver node of the wireless magnetometer for vehicle count and monitoring on Thingspeak dashboard.

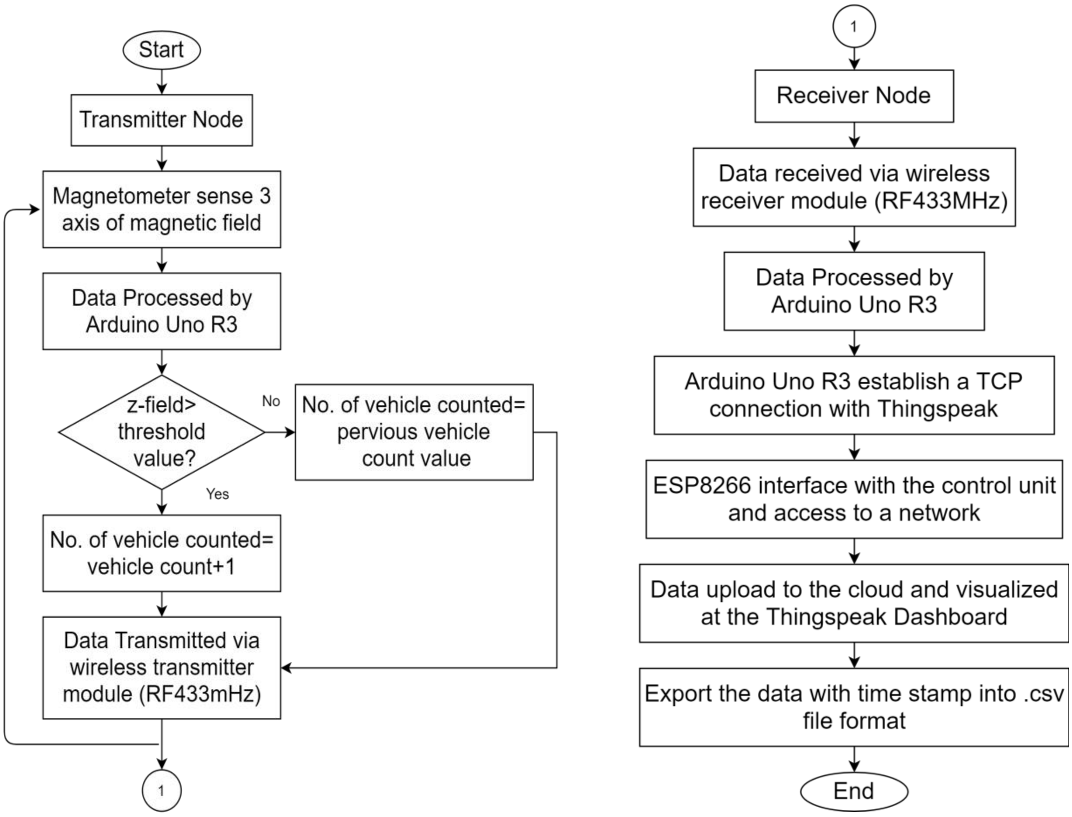

Figure 2: Operation of the transmitter node and receiver node of the wireless magnetometer for vehicle count and monitoring on Thingspeak dashboard.

3. Results and Discussion

The prototype build as shown in Figure 3 was capable of collecting the number of vehicles passed by data and upload the data to the cloud and able to be monitor through an IoT platform such as Thingspeak Cloud server. Calibration of the threshold level for the z-axis of the magnetometer sensor had done so that the threshold value selected is suitable whereas smaller vehicles unable to be detected if we set it very high and high percentage of vehicles that pass in the lane which no sensors was embedded in the road will be detected if we set it very low which may affect the accuracy of the data collected. The real time implementation of this wireless magnetometer is setup whereas the distance between transmitter node and the receiver node started in 1m as shown in Figure 4. Increment of the distance in between two nodes is by 1m. The car with speed 30 kmph will drove passed the sensor which place on the ground starting from 1m to 5m.

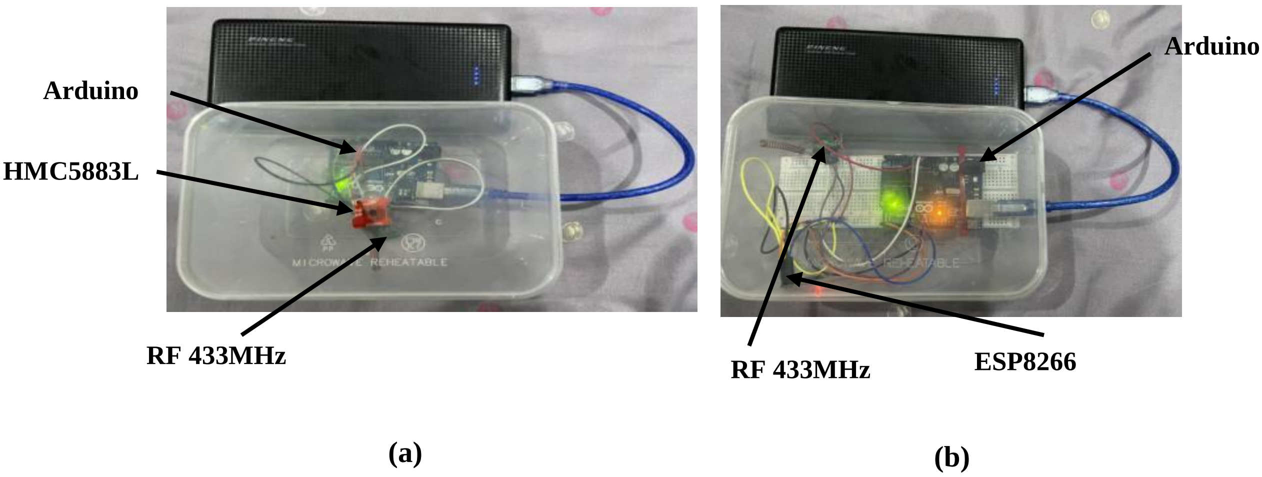

Figure 3:(a) Prototype transmitter node. (b) Prototype receiver node.

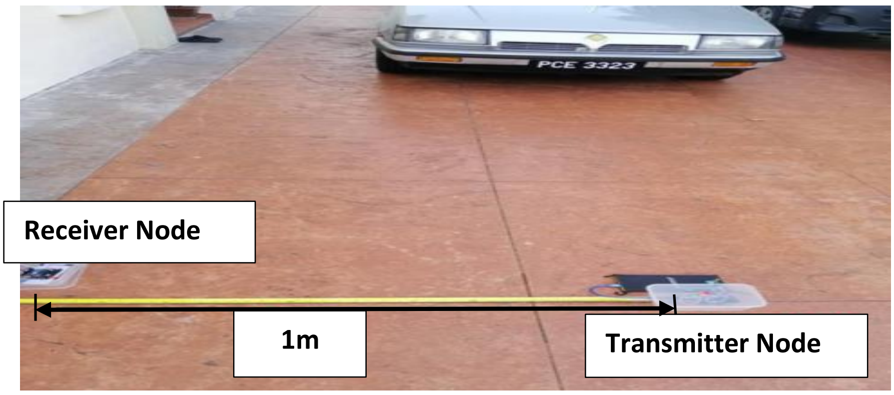

Figure 4: Prototype real-time implementation setup.

3.1 Magnetic Field

Figure 5 shown the pattern of the magnetic field based on the readings of the x, y, and z-axis obtained via the sensor placed on the road as well as the number of vehicles counted which shown in the Serial Monitor of the Arduino. The threshold is now set to 100 where when the z-axis was above 100, the counter will start to count. As when there is no ferrous object been sensed by the sensor within 12 seconds, the counter will remain its previous value as current value. In the absence of car, the number of vehicles counted remained 0. Whenever the sensor sensed the ferrous object which is the car had drove across the top of the sensor, the magnetic fields was distorted and the magnetic reading of z-axis will immediately gain above the threshold level and the counter will incremented by one. If the car is stayed on top of the sensor, the magnetic reading of the z-axis will gain a value more than the limit, the counter will stop its increment. Once the ferrous object leaves the sensor, the magnetic fields will return to it constant state. The waveform obtained are not uniform. This may be due to some ferromagnetic parts had pass over the sensors and create extra fluctuations in the signal**.**

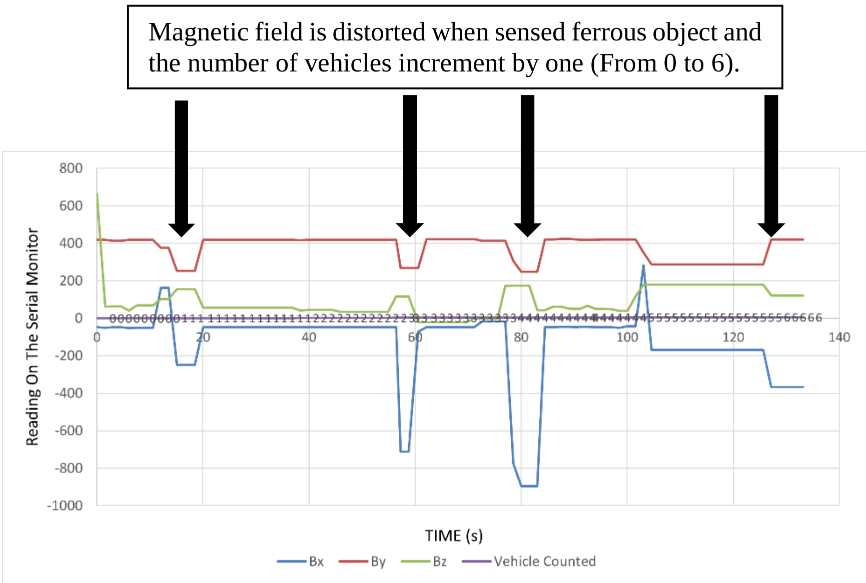

Figure 5: Pattern of the magnetic field when the car drove across the sensor for six times.

3.2 The Testing of Magnetometer Functionality

Functionality testing was done to verify the magnetometer sensor able to detect the number of vehicles in four situations (car absence, car slide into the sensor, car on top of the sensor, and the car drove away from the sensor) shown in Table 1. The transmitter node and receiver node's distance is set within one meter with the car speed of 30 kmph upon the testing. The limit of the magnetic (z-axis) value was set above 80. Both sets of nodes are functional where they can transmit and receive and upload to the Thingspeak. Set 1 with three different conditions is tested to verify the magnetometer sensor's ability to detect the vehicle. In comparison, Set 2 with four different conditions is tested to observe the number of vehicles counted when there is no new disturbance of the z-field (the vehicle stays on top of the sensor). In Set 1, we successful verified the sensor worked properly such that no vehicle is counted for car absence condition as there is no distortion of the magnetic field (z-axis) or there are no ferrous materials passed through the surface of the sensor, which results from the z-axis is below than its limits. When the car started to drove across the sensor, distortion of the z-axis occurred as its value detected is above 80, the number of the vehicle is counted. In Set 2, we can conclude that the counting of vehicles will only start once the detected z-filed is over the threshold limit (80), or else it would remain the same as the previous value. This situation can be seen in Set 1 with three conditions and Set 2 with four conditions where the number of vehicles stops counting whenever the car stops on top of the sensor or passes by the sensor. In another word, the increment of the counting will continue again once the next car approaches the sensor.

Total of 5 car is tested where the sensor managed to count the same number of vehicle and upload the latest data towards the Thingspeak which as shown in the Figure 6 and 7. Figure 6 had included the device’s real-time location, number of vehicle count in matrix form, magnetic field (x,y,z) data in matrix form. Each data against time is automatically plotted in line chart forms and visualized in the dashboard, as shown in Figure 7. This allows the user to analyzed the traffic data and observed the magnetic field pattern over a specific time rather than matrix forms. The user is allowed to export those data in .csv file format with a recorded data time stamp.

Table 1: The functionality testing for the sensor in the four different events.

Set	Conditions	Reading of magnetic field (z-axis)	No. of Vehicle Counted
1	Car Absence	-55	0
	Car drove across The Sensor	108	1
	Car Drove Away from Sensor	2	
2	Car Absence	2	1
	Car Drove Across The Sensor	92	2
	Car On Top of The Sensor	92	
	Car Drove Away from Sensor	17	

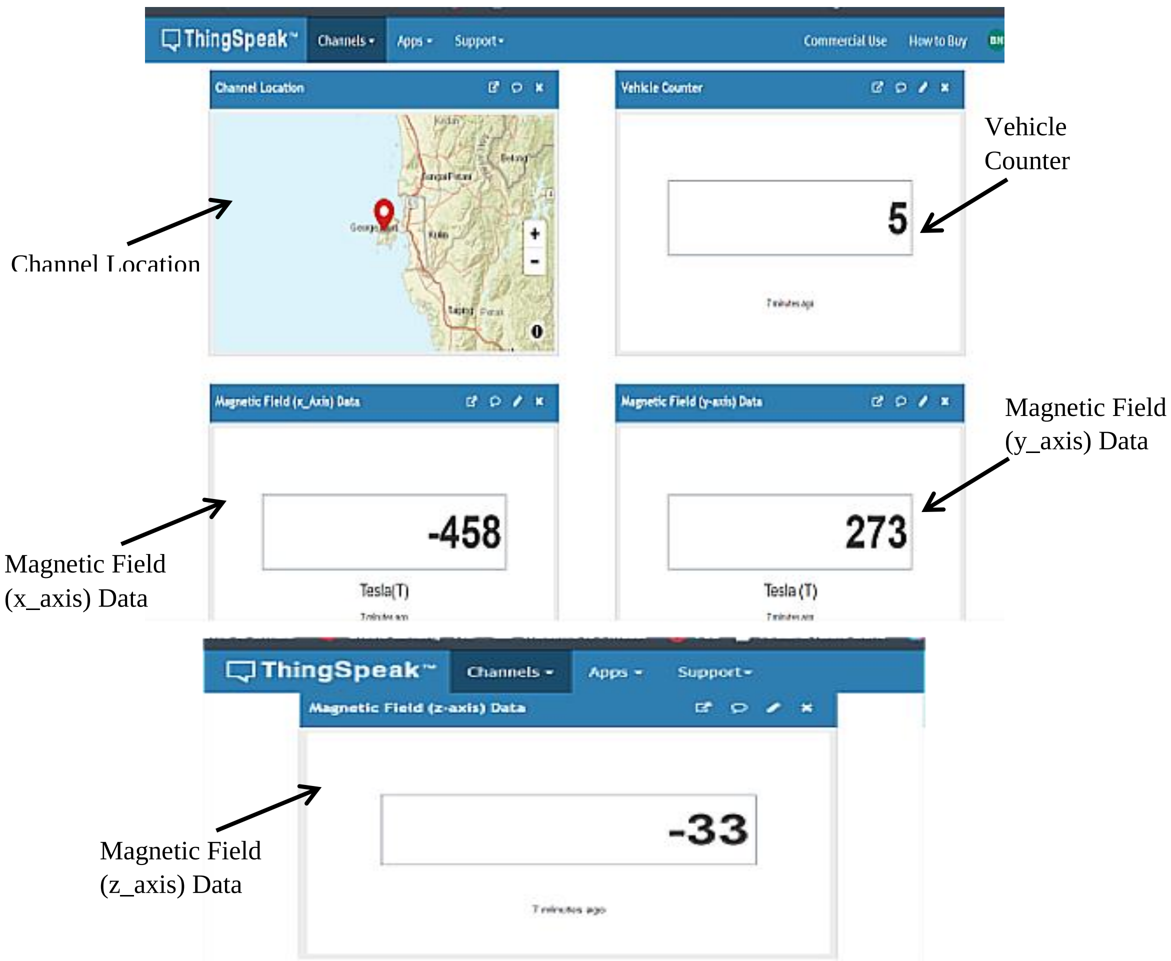

Figure 6: The latest magnetic field data (xyz axis) and the number of vehicle count displayed on the dashboard of Thingspeak in matrix forms in the event of car drove across the sensor.

Figure 7: (a) The latest magnetic field in x-axis data displayed in line chart forms where the magnetic flux against the time. (b) The latest magnetic field in y-axis data displayed in line chart forms where the magnetic flux against the time. (c) The latest magnetic field in z-axis data displayed in line chart forms where the magnetic flux against the time. (d) The latest number of vehicle counted against time is displayed in line chart forms.

3.2 Signal Strength

The signal strength between the transmitter and receiver tested by adjusting the distance between both modules from 1 to 5 meters with the increment of 1. The signal strength was tested to checked if the distance between transmitter and receiver will effect the real-time delay of the transferred data. From there, we had obtained the average real-time delay. The signal strength between the transmitter and receiver modules was excellent such that it around 1 second to 1.3 second of real-time delay. However, the results were inconsistent because there might be noise or others signal interference with our RF signal. There are some other factor that affecting the signal strength other than distance between transmitter and receiver such as the environmental factor, materials used and speed of the vehicle that pass through the magnetometer. Many previous study used Received Signal Strength Indicator (RSSI) measurement system to check the signal strength of the sensor used. RSSI measurement system will collect the data of signal strength in decibel which is a basic unit of RF power measurement[13]. Magnetometer is easier to install compare to some other sensor but it must be installed inside or close to the traffic lane.

3.4 Accuracy of detection

Figure 6 shows the accuracy of the wireless magnetometer sensor. The real-time vehicle had passed through the sensor 50 times for testing the accuracy of the prototype. The number of vehicles detected by the sensor compared to vehicles passed in conjunction with the increment of 1 meter to 5 meters for the distance between transmitter and receiver. The counting accuracy has also been determined. When the transmitter and receiver's distance is 1 meter, it had a high percentage of counting accuracy, which is 96%, whereas 48 detected vehicles out of 50 vehicles passed the sensor. The counting accuracy decreases because the distance is increased due to the real time delay in the RF transmission. However, the counting accuracy is still maintained above 80%. This result shows that the RF receiver must be installed above ground of the roadway for the line of sight in the RF communication so that the transmission signal is not influenced by any obstacle to ensure the transmission speed so that no delay in capturing results and uploaded to the IoT platform. The sensor node should be intrusive on the roadway to detect each vehicle passed by the sensor. The detection rate obtained is different from the previous study [12] in terms of the sample data and experiment setup in the roadway. Our experiment used a fixed number of cars passed the sensor placed on the middle of the roadway and tested the accuracy in each distance between the sensor node and the receiver node. The minimum value of this vehicle count system accuracy is 84% with distance of 5 meter between transmitter and receiver node. In contrast, the previous study used a random sample with camera validation 4 hours on the highway, and this study did not test the accuracy for the distance between the transmitter node. Our experiment provides more useful data in determining the sensor node's placing and its receiver in real-time traffic testing.

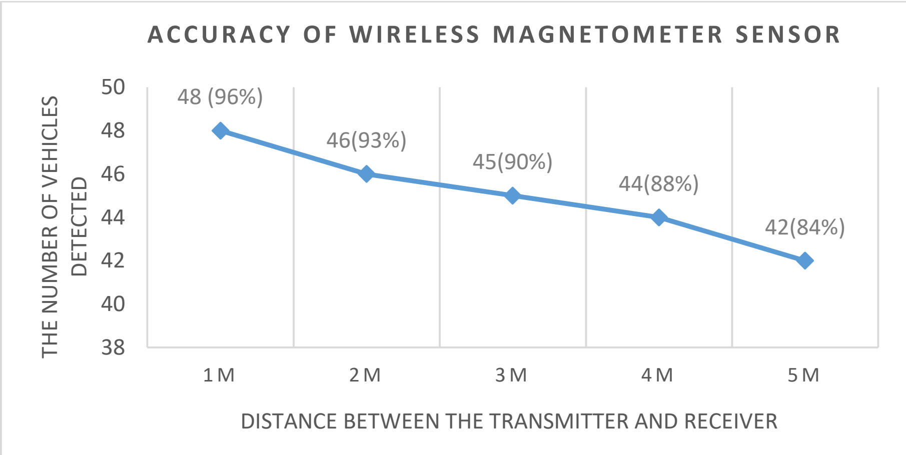

Figure 6: Accuracy of the wireless magnetometer sensor.

4. Conclusion

In this study, number of vehicle in real-time was successfully monitored in four types of situations through Thingspeak. The number of vehicle is counted with the change of Earth's magnetic field (z-field) through the fixed threshold value when passing through the magnetometer sensor HMC5883L. Transmitter and receiver nodes was developed by using magnetometer sensor HMC5883L and RF 433MHz transceiver. A gateway which was Thingspeak IoT platform also developed to display the number of vehicle in real-time on computer or mobile phone. The signal strength between the transmitter and receiver modules was tested excellent with the distance increment of 1 meter to 5 meters which approximately around 1 second to 1.3 second of real-time delays. Pattern of the magnetic field based on the readings of the x, y, and z-axis was observed. The signal tansmission is within a distance of 5 meters between transceivers and a latency of 15 seconds to the Cloud. The developed current prototype is only suitable for implementation in one lane road because the distance between transmitter and receiver node is limited as the longer the distance between transmitter and receiver node, the lower the device accuracy.

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