

Design and Development of IoT based Sensor for Traffic Management

Tunggul A. Nugroho, Sinung Suakanto, Herman Y. Sutarto, and Endra Joelianto

Abstract— The increasing number of vehicles causes traffic problems at several points in big cities. A traffic management is needed to control the signalized intersection. In traffic management, one important parameter is travel time. In this paper, we develop IoT hardware intended to record the critical information that characterizes the movement of vehicles. Data from the movement of the vehicle will contain information on the position and speed of the vehicle and the recording time. The system is designed and developed by starting from sensor, controller, communication, broker and data logger. The communication protocol used is open source MQTT protocol for communication from device to server. The results of the design are tested in several streets around city of Bandung, Indonesia. The results are accommodated in a server. The recorded collection of data can be exported as bulk data for further analysis or development of traffic management models. This paper presents the the design and performance of the developed IoT device for traffic data management. succeeded in The continuously sending data of sensor to the Data Logger with a period less than 1s was achieved.

Index Terms—speed and position sensor, IoT, Traffic management

I. INTRODUCTION

THE problem of traffic congestion in urban areas require an urgent and comprehensive solution. The solution that has so far been pursued by the government as a regulatory agent is to intensify the development of road facilities. One potential solution that has not yet been intensified is the development of intelligent transportation systems where the important and crucial element is the development of coordination between traffic lights at intersections in an urban area.

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Various works have been built related to developing intelligent transportation. Some of our previous work has developed estimation models for urban traffic flow [1]-[3]. From previous work, we have successfully created a technique for developing coordination between traffic lights at intersection. To provide simulations that are close to real conditions, traffic parameters are needed that are close to actual conditions. In some cases, parameters related to traffic indicators are obtained by installing sensors placed at the intersection. This data retrieval process using sensor will costly especially if in a city has many intersections and road.

The coordination of traffic lights requires the development of means of monitoring traffic variables such as density [4], traffic volume [5], [6] and travel time at each crossing arm in a certain area. The ability to monitor these variables enables the development of an adaptive control system of traffic lights that coordinate with each other in an area of the city. The design of this coordinated control system is a combination of a distributed model of predictive control system at each intersection with a perimeter control system for several boundary areas between sub-areas (regional). Each of these sub areas is model using a Macroscopic Fundamental Diagram (MFD) [7]. Sub-area classification is determined by the topology and traffic flow characteristics in a city, whether based on a particular corridor zone or downtown zone with its surroundings [8].

The development of a coordinating control system can be divided into two stages, namely: (1). the development of a distributed predictive control (MPC) system at each intersection; (2) development of MPC integration with perimeter control based on MFD [9]. The development of density monitoring can be done if both travel time monitoring and traffic flow monitoring can be applied for each link. Instead of using sensors that are installed statically at an intersection, mobile sensors will be used in vehicles. The more moving sensors that are used, the more information will be collected related to these parameters. Information from the vehicle's position and speed at whole time can be processed into information such as travel time and traffic flow in the link. In addition, information about travel time will be useful as one of the model validation tools in the traffic micro simulator.

II. RELATED WORK

Travel time is the duration of the vehicle moving from x_1 to x_2 [10]. Travel time is defined as the total time for a vehicle to travel from one point to another over a specified route, taking into account the stops, queuing delay and intersection delay [11]. The average travel time can be used as for many purposes related.

Travel time can be used as basis for many intelligent transport systems (ITS) applications and traffic management functions [10]. Sometimes it can be defined as Advanced Traffic Management Systems (ATMS) and Advanced Traveller Information Systems (ATIS). ATMS are usually used by traffic engineers in order to enhance mobility and obtain a more efficient and safe traffic in road networks [10]. It can be used to design the traffic profile to determine green light duration on the cross section. In the other hand, ATIS are usually to provide commuters with the necessary traffic information and some tools to support decision-making [10].

There are many previous studies on the travel time measurement. Some technique for travel time measurement can be:

- Vehicle Passage Detection: For example, using fix sensor Detector, Bluetooth [12], [13]
- Continuous Vehicle Tracking. For example, using: GPS [14]-[17]
- Automatic vehicle identification (AVI). For example, using: RFID [18], video camera [19] and WiFi [20]

With RFID sensor-based technology, it used antennas that installed at each intersection. It also requires that each vehicle mounted with a sign / sticker as an object identification. This approach is also considered to be too expensive because it needs RFID reader at each intersection which is more or less the same as the fixed sensor approach.

Sensor with GPS is one system that has the potential to provide tracking information with good accuracy [5]. The advantage of using GPS is cheaper, ease installation and especially has a very wide coverage capability [5]. We can describe the use GPS to collect traffic information as figure below.

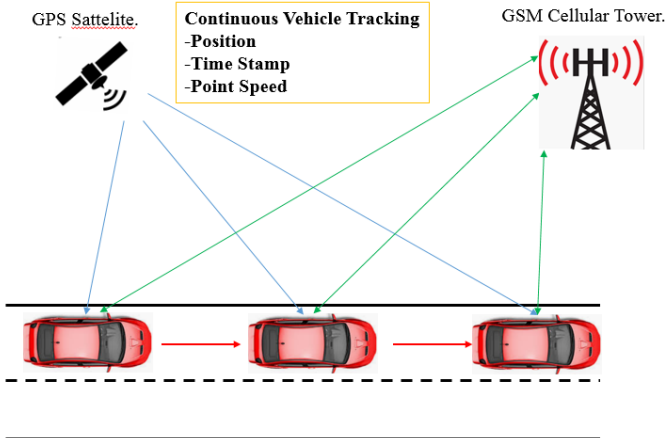


Fig. 1. Continuous Vehicle Tracking.

Generally, the travel time is caused by the situation will be perceived by all vehicle entering the link and is caused the delay due to traffic light. Travel time is the sum of two independent random variable: delay time and free flow travel time.

$$\begin{aligned} y_{x1,x2} &= \delta_{x1,x2} + y_{f:x1,x2} \\ y_{f:x1,x2} &= p_f(x_1 - x_2) \end{aligned} \quad (1)$$

Based on (1), we can derive the probability density of travel time and along with a dynamic model of traffic flow, turning behavior of an intersection, we can estimate the travel time in a certain link [5].

Measurement of travel time in real time can be used to validate of the traffic model of urban network through the result of estimated travel time. The validation is implemented in micro-simulator. Many studies also carry out to estimates and predictions for travel time [6], [10], [11], [21]-[23]. This method can be combined with travel time measurement to provide more accurate and more available for traffic management purpose.

Therefore, in this paper, it is proposed GPS-based sensor that can logged speed, position and log time. From this information, it can deliver information of travel time. The paper proposes a system that can send data from GPS sources and used the principle of IoT (Internet of Things) with MQTT protocol (Message Queue Telemetry Transport).

Some researchers have also developed the use of GPS or another sensor for data collection with IoT technology [24]-[28]. However, none of them explained how the data information can be used for traffic analysis and management. We conduct research to develop device or GPS-sensor that can be used as data logger for processing traffic information.

III. SYSTEM DESIGN

In this research, we develop IoT System for collecting traffic information with architecture as shown in figure below.

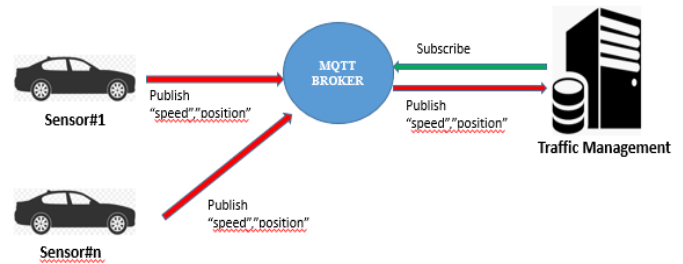


Fig. 2. Speed and Position IoT.

The sensor (basically GPS-sensor) will periodically deliver the information consist of vehicle speed and vehicle's position to the MQTT Broker. The client will subscribe to topics to get information periodically as well. To get more precise data resolution (sampling), the desired sampling period is for about 1-5 seconds.

A. General Requirements

General requirements for the system are defined as follow:

1. The device is able to periodically send data (speed, position and logging time)
2. The sensor is able to store speed and position data offline and stored in memory
3. All information about speed and position data are transmitted wirelessly to the server
4. The period of sending data to the server is less than 5 seconds
5. Offline data storage sampling is updated every 1 second
6. The sensor works with the power supply of the car / motor with a voltage range of 12-24 VDC
7. The sensor is packed with the smallest size possible

B. Block Diagram of Hardware

From the general requirements above the block diagram, we propose our system as follows:

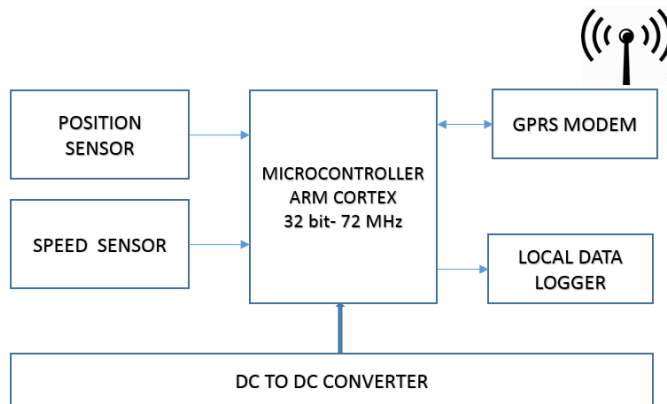


Fig. 3. Block Diagram.

The device is built using a microcontroller. The main input of the device is the position and sensors. Data collected from these sensors will be sent to the data center via the GPRS modem module. In addition, the sampled data will also be stored as a local data in a local data logger module.

For the purposes of online analysis, data can be used from the server. The data logger itself is used as data backup; offline processing; or as a fail-over when the communication module is communication failure. Communication from the device to the data center (server) uses a protocol that is often used in IoT called as MQTT protocol.

C. Communication

Communication between sensors to the server uses MQTT protocol. The MQTT protocol utilizes the basic concept of publish-subscribe. The device will send data using the "publish" channels with specific topic name for example "Topic 1". This message will be sent via MQTT Broker and the client will receive it using "subscribe" channel with same topic name. MQTT protocol that will be implemented is with QoS = 0 as follows:

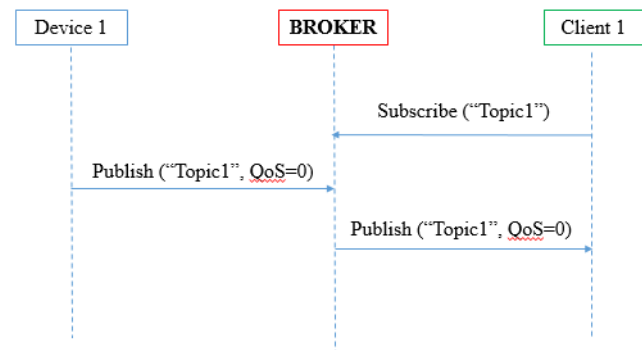


Fig. 4. IoT Speed and Position Protocol.

The data consist of several components, i.e. sequence, Date, Time, Lat, ExtLat, Long, ExtLon, Speed, X, Y, Z

- Sequence: is data sequence numbering, so that it can be detected if there is data that is not in order
- Date, Time: is the time-stamp time when data is taken from the sensor
- Lat, ExtLat: latitude is a geographic coordinate that specifies the north – south position of a point on Earth's surface
- Long, ExtLon: is a geographic coordinate that specifies the east – west position of a point on the Earth's surface
- Speed: is speed data at the current position

D. Component Selection

The main components used in this system include: sensor, microcontroller and GPRS Modem. Position and speed sensors use GPS (Global Position System) to extract information of position and speed. There are many choices for position sensors, but in this case, we choose manufacturer's GPS Sensor from Global-Top with Type FGPMOSL3C.

Whereas the microcontroller will use the ST manufacturer's, a 32-bit 72 MHz microcontroller type STM32F103. In this case multiple processors will be used to handle a variety of different tasks. For local data loggers Atmega328 is used. For GPRS Modem the manufacturer uses simcom.com with SIM800C Type.

E. Schematic Design

1) Speed-Position Sensor and Main Controller

From the data sheet, we can make device as schematic diagram as follow:

Main Controller uses ARM Cortex Microcontroller Type STM32F108 components with the following basic circuits:

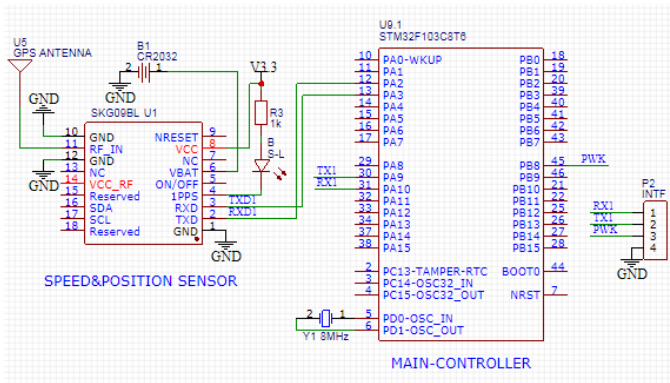


Fig. 5. Main Microcontroller.

There are several additional components to support its work such as the 8 Mhz Crystal Oscillator etc.

2) GPRS Modem schematic

GPRS Modem is used to send data to the Cloud, with the following basic framework:

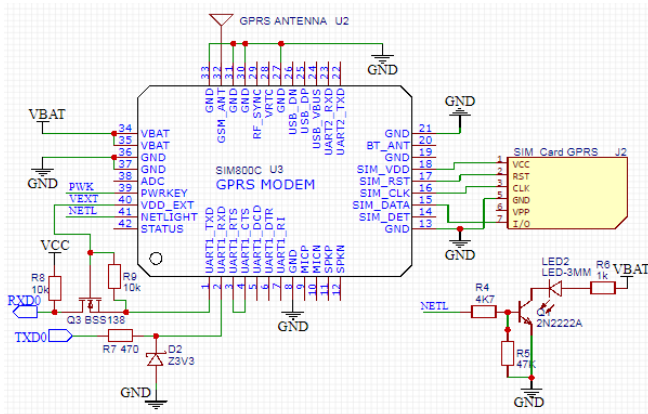


Fig. 6. GPRS Modem.

It should be noted that the voltage level of the SIM800C is different from Atmega128, so we need a translator level from 3.3V to 5V using N-Channel Mosfet type BS-138. Instead to change the level of 5V to 3.3V using a 3v3 Zener Resistor and Diode.

3) Local Data Logger schematic

Local Data logger is used to record the data if the communication is failed, so that data can still be recorded. Data recording is design periodically for about every 1 second.

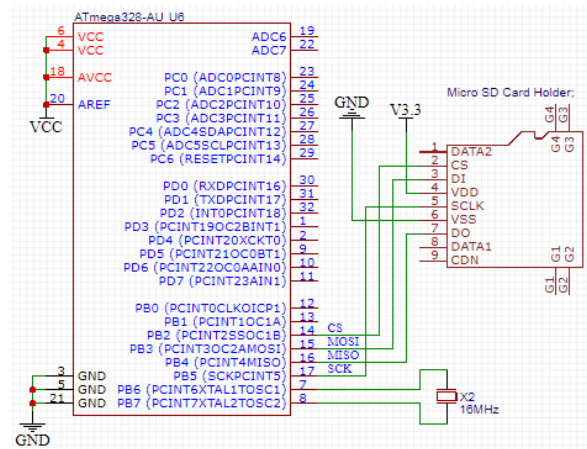


Fig. 7. Local Data Logger.

Data Logger uses SD-Memory of 4 GB so that it can store for 1 month with FAT-32 format

4) Software Design

The design of Main Microcontroller software can be explained as a flow charts as shown in Fig. 8:

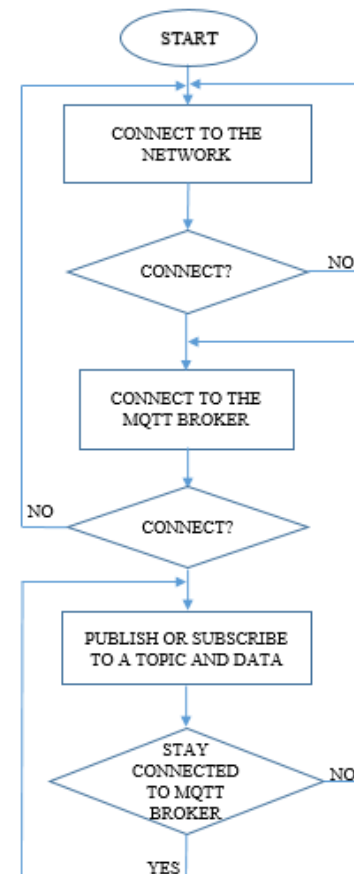


Fig. 8. Flow Chart Main Microcontroller.

IV. IMPLEMENTATION

After the schematic phase then we designed the PCB with tools with the following results and the picture of PCB Layering can be shown as 2 pictures below.

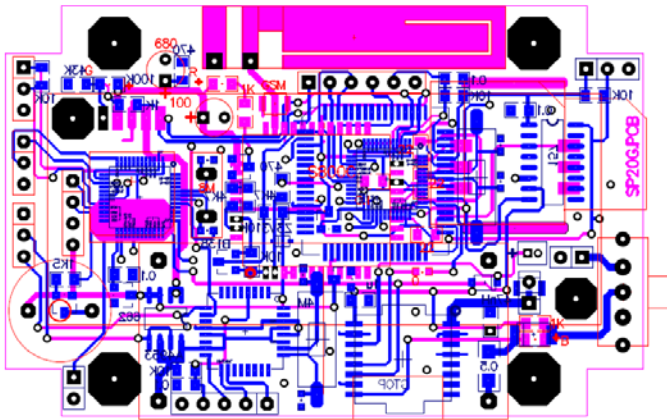


Fig. 9. PCB Prototype.

We carry out several components measurements and tests to ensure each component functioned properly as follows.

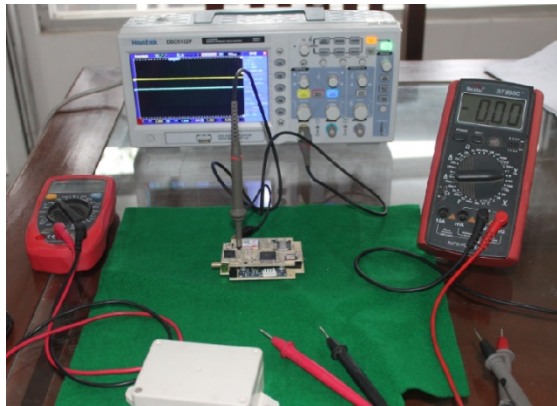


Fig. 10. Lab. Prototyping and Testing.

We made the prototype by installing all of components and making sure all components were able to run well. The result of our prototyping can be shown as 2 picture below.

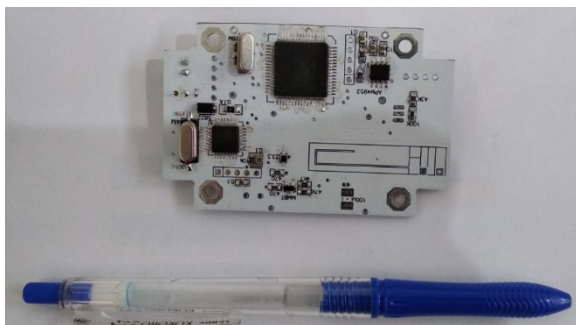


Fig. 11. Prototyping Top Layer.

Further, we make the box as the main container of the device. The sample result of our box can be shown as picture below.

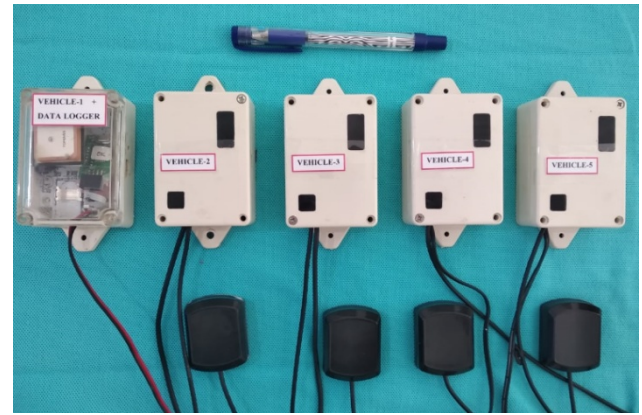


Fig. 12. Assembly and boxing.

We also design the application that will be used to store logged information in the database server. From the information we can also view and analyze the data previously stored at the application. The sample of application on the cloud server [<http://103.27.207.134/tda2019>] could be seen in the pictures below.

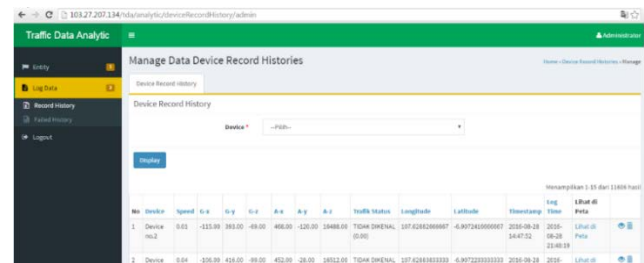


Fig. 13. Result on Server Data Logger.

We can also view position of the vehicle in real map using Google Maps seen in the picture below.

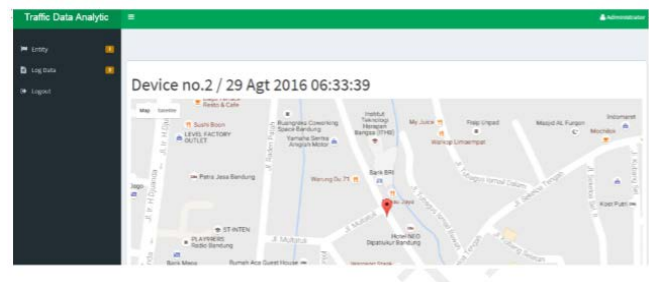


Fig. 14. Vehicle Position on the map.

V. RESULT AND DISCUSSION

After the device is ready, we prepare for testing. The testing is carried out by installing the device in a motorcycle as vehicle tester. The device installation can be seen in the picture below.

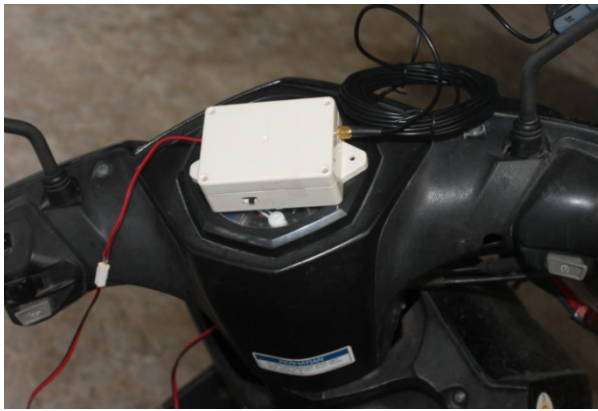


Fig. 15. Testing using Motorcycle.

Another testing is also carried out in the car as a testing vehicle. Examples of installation look like in the picture below.



Fig. 16. Testing Using car.

The test scenario is carried out to measure the speed, position of the vehicle at several points in some period of time. The testing vehicle will travel on the streets of Bandung, Indonesia. The vehicle will pass through several period, especially traffic jam points. Every movement of the vehicle will be recorded by the device. The parameters recorded mainly are position of vehicles, speed and logging time.

The movement of the vehicle at the times can also be seen in the map. We make some experiments in specific streets in Bandung, Indonesia to get information travel time with path as shown below.

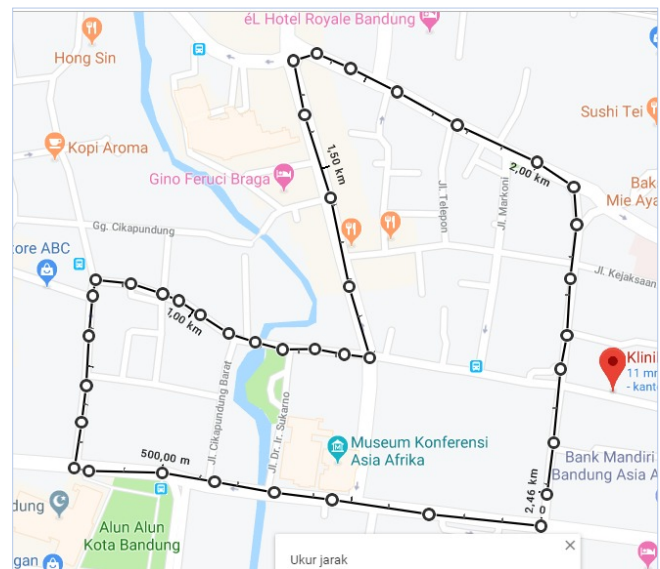


Fig. 17. Vehicle Movement on the map.

From this map, we want to get information of traffic in some street especially in link-i and link-j like figure below.

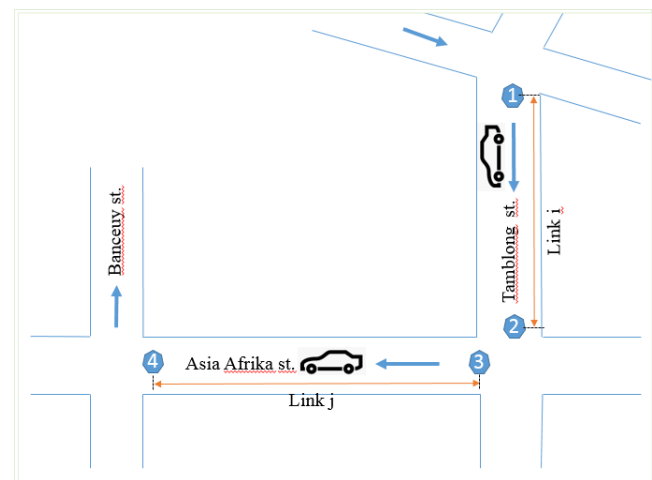


Fig. 18. Measurement Travel Time for Some Link in Bandung, Indonesia.

Some examples of the results of testing can be seen as in the Table I.

TABLE I.
RESULT FOR LINK-I

Duration	Travel Time (s)	Avg.Speed
12.17-12.20	211	9.62
12.30-12.33	249	8.74

TABLE II.
RESULT FOR LINK-J

Duration	Travel Time (s)	Avg.Speed
12.20-12.23	230	12.5
12.33-12.35	178	15.34

This information was summarized from detailed data logger resulted from real measurement using GPS-sensor. Some samples of data can be read from APPENDIX.

Vehicle speed fluctuation at each link can be observed. For example, it is shown in the graph below for link-i.

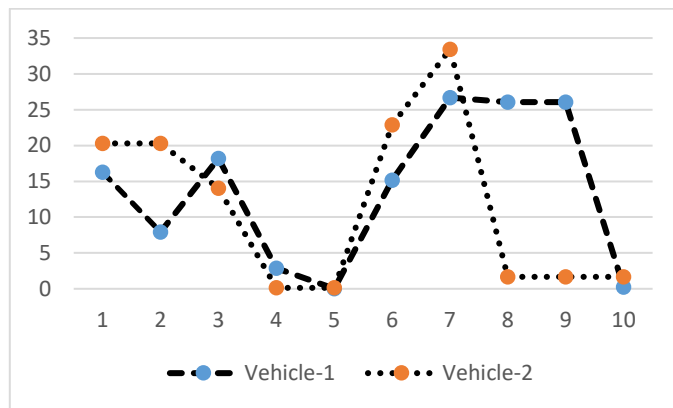


Fig. 19. Speed Fluctuation in Link-I.

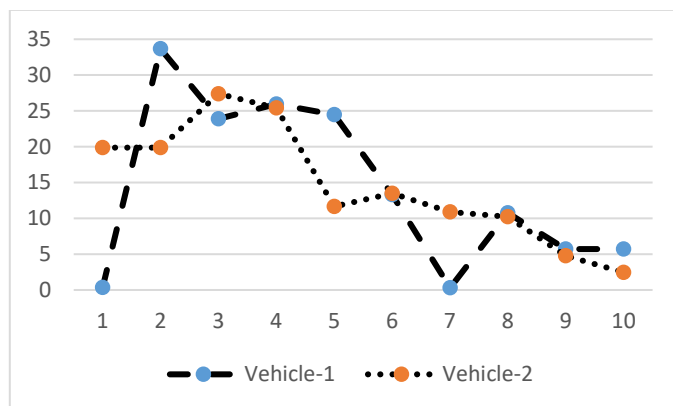


Fig. 20. Speed Fluctuation in Link-J.

Based on testing the system that has been built, implemented and tested in the field, the following results are obtained:

1. The sensor succeeds in sending data continuously to the Data Logger with a period of <1 second
2. The system is able to accommodate the results of position and speed sensing data
3. Data Logger results can be used for traffic management analysis.

It can be observed one by one via the application in the cloud. Also, from the collection of data that has been recorded, we can export it as bulk data for further analysis or development of other models. It can be proposed for our further work.

By using the results, in the future, we can get more information such as:

- Consistent measurements using several vehicles in a particular region and a certain time frame will provide sufficient database availability for further analysis.
- Some analysis that can be developed such as determining the point of congestion, estimation of

queue length on a certain road, queue speed, etc. based on these data.

- Create a traffic profile of several roads without having to carry out manual measurements on several roads. An automation breakthrough to get congestion profile data on a certain road and a certain time.

VI. CONCLUSION

In the paper, IoT devices for traffic data management were developed and prototyped from sensor, controller, communication and data logger. It was also developed simple application at the cloud server [<http://103.27.207.134/tda2019>]. Based on testing of the system that was built, implemented and tested in the field, the sensor succeeded in sending data continuously to the Data Logger with a period of <1 second. For testing, vehicles that traveled around in some streets in the city of Bandung, Indonesia. The results were collected in a server. The collection of data was recorded and can be exported as bulk data for further analysis or development of traffic management parameter to build model or simulation.

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APPENDIX

TABLE III
LOGGER VEHICLE-1 LINK-1

Speed (km/h)	lat	long	log_time	Travel Time link-i (s)	speed avg (km/h)
16.26	-6.918134	107.6125	019-08-18 12:17:4	211	9.62
18.19	-6.918554	107.6124	019-08-18 12:17:5		
18.19	-6.919559	107.6123	019-08-18 12:18:1		
0.04	-6.919614	107.6123	019-08-18 12:18:3		
15.15	-6.920197	107.6122	019-08-18 12:18:5		
26.08	-6.921146	107.6120	019-08-18 12:19:0		
0.24	-6.921267	107.6120	019-08-18 12:19:2		
0.17	-6.921238	107.0000	019-08-18 12:19:4		
0.31	-6.921212	107.6120	019-08-18 12:19:5		
0.35	-6.921494	107.6120	019-08-18 12:20:1		

TABLE IV
LOGGER VEHICLE-1 LINK-J

Speed (km/h)	lat	long	log_time	Travel Time link-j (s)	speed avg (km/h)
0.35	-6.921692	107.6119	019-08-18 12:20:2	230	12.50
28.04	-6.921572	107.6106	019-08-18 12:20:3		
21.71	-6.921484	107.6098	019-08-18 12:20:5		
7.09	-6.921361	107.6090	019-08-18 12:21:0		
-	-6.921291	107.1171	019-08-18 12:21:3		
10.76	-6.921259	107.6082	019-08-18 12:21:4		
5.70	-6.921215	107.6078	019-08-18 12:21:5		
10.82	-6.921154	107.6074	019-08-18 12:22:1		
12.45	-6.921095	107.6069	019-08-18 12:22:3		
1.50	-6.921066	107.6066	019-08-18 12:23:1		

TABLE V
LOGGER VEHICLE-2 LINK-I

Speed (km/h)	lat	long	log_time	Travel Time link-i (s)	speed avg (km/h)
20,32	-6.918189	107.6124	2019-08-18 12:30:36	249	8,74
14,02	-6.918865	107.6123	2019-08-18 12:30:55		
0,13	-6.919758	107.6122	2019-08-18 12:31:47		
0,13	-6.919770	107.6122	2019-08-18 12:31:58		
33,45	-6.920821	107.6121	2019-08-18 12:32:24		
1,67	-6.921488	107.6120	2019-08-18 12:32:32		
1,67	-6.921488	107.6120	2019-08-18 12:32:53		
1,67	-6.921492	107.6120	2019-08-18 12:33:12		
0,09	-6.921492	107.6120	2019-08-18 12:33:29		
19,89	-6.921723	107.6119	2019-08-18 12:33:45		

TABLE VI
LOGGER VEHICLE-2 LINK-J

Speed (km/h)	lat	long	log_time	Travel Time link-j (s)	speed avg (km/h)
19.89	-6.921723	107.6119	019-08-18 12:33:4	178	15.34
19.89	-6.921575	107.6105	019-08-18 12:34:0		
27.39	-6.921447	107.6095	019-08-18 12:34:1		
25.41	-6.921371	107.6088	019-08-18 12:34:2		
11.63	-6.921309	107.6083	019-08-18 12:34:3		
13.48	-6.921265	107.6080	019-08-18 12:34:5		
10.91	-6.921188	107.6076	019-08-18 12:35:0		
10.20	-6.921125	107.6072	019-08-18 12:35:1		
4.76	-6.921092	107.6069	019-08-18 12:35:2		
3.46	-6.921070	107.6067	019-08-18 12:35:4		

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