An Ultrasonic Sensor-based Traffic Mapping Application for Cebu City

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Abstract—**The current traffic status in Cebu City is increasing the travel time of citizens going from one place to another; to address this problem, an alternative traffic flow monitoring system is proposed. The system will be an ultrasonic sensor-based traffic map application which will show traffic flow data to traffic management personnel in order for them to monitor Cebu City's traffic. It will be using ultrasonic sensors for data gathering and a sensor network for communication integrated in a microcontroller in order for a mapping application to display the traffic flow data. This will serve as a basis in decision-making for traffic management organizations to utilize as it cannot reduce traffic by itself since it only maps out traffic flow.**

Keywords— sensors, traffic, mapping

I. INTRODUCTION

With growing populations, more and more commuters travel around the city [1]. Traffic dramatically lengthens commute times from home to work. The unresolved traffic congestion in Metro Cebu has resulted in at least Php 1.1 billion in economic losses a day, according to initial results of a study being conducted by the Japan International Cooperation Agency (JICA) [2]. According to the 2017 data from the Land Transportation Office, there are 574,819 motor vehicles in Cebu Province; and it is expected to increase to at least 800,000 by the end of the year having the commuters in Cebu to wait in unmoving traffic [3]. Work hours can be delayed, and even be changed due to the amount of time taken up by traffic.

The increasing number of vehicles, the government's failure to construct more road networks or even widen the existing roads and the problem about undisciplined drivers are the main reasons why the roads in Cebu City have become congested [4].

Within Cebu City, motorists usually experience heavy traffic from seven to nine o'clock in the morning and five to seven o'clock in the evening, particularly in Governor Mariano Cuenco Avenue. This is also experienced in General Maxilom Avenue, Osmeña Boulevard, Imus Avenue, Natalio Bacalso Avenue, B. Rodriguez Street, Escario Street and Gorordo Avenue. In fact, motorists in Cebu City still move at 22 kilometer-per-hour (kph) even during peak hours [4].

Aside from the increasing volume of vehicles, Cebu City is also faced with a defective traffic control system. The defective electronic traffic control system called SCATS or Sydney Coordinated Adaptive Traffic System installed in 1990 can no longer coordinate the signals from one intersection to another [4].

The gadgets buried beneath the road near the intersections are designed to transmit signals to the main traffic control [4]. When the gadgets were still working, these were able to automatically adjust the signal's pre-timed phase lengths in response to traffic flow. If the sensor does not detect any vehicles, the controller automatically transmits a red signal and simultaneously a green signal for the other side of the road. The cost of the repair and renovation, including the purchase of extra spare parts, is about Php 163 million [4].

The traffic monitoring system in Cebu City is dependent on the traffic field personnel deployed in the streets. The deployment of the traffic field personnel at various intersections and at the mid-blocks is very necessary even if these intersections were already installed with traffic signal lights. The traffic enforcers are the ones responsible for the direction and control of vehicular traffic flow especially during peak hours, to respond to any vehicular traffic accident in the area and to enforce the Traffic Code of Cebu City in cases when violations are observed [5].

According to the acting department head of the Cebu City Transportation Office (CCTO) in 2016, lawyer Rafael Christopher Yap, the increase in automobiles or private vehicles is the number one reason behind road congestion in Cebu [6]. Aside from the growth of vehicle purchase and vehicle registration, lack of discipline on the part of drivers and pedestrians also adds to the traffic situation. In the survey conducted by the navigation application, Waze, Cebu City was the worst place in the world to be a driver. Lack of discipline makes traffic in Cebu worse due to no clear stops for vehicles and no proper bay for alighting passengers [7].

Having a traffic monitoring system can help alleviate traffic congestion and improve road safety. The use of real-time data for traffic management in the Philippines will help city planners to improve transport efficiency competencies [8]. With that being said, the researchers proposed a sensor-based traffic mapping application that can potentially aid traffic management organizations in monitoring traffic flow. To help mitigate the traffic situation, the following technologies can be used: MB1010 LV-MaxSonar-EZ1 ultrasonic sensor, Arduino Uno, LoRa (Long Range) RFM95 Shield, and QGIS (Quantum Geographical Information System).

Ultrasonic sensors operate by transmitting ultrasonic energy and measuring the energy reflected by the target. The MB1010 LV-MaxSonar-EZ1 ultrasonic sensor has virtually no dead zone which offers very short to long range detection with low power consumption. The aforementioned ultrasonic sensor is ideal to be used for the system since it can be operated from 2.5 to 5.5V and can be powered by different types of power source [9].

Arduino Uno is a microcontroller board which allows users to develop applications used for research. Microcontrollers are small, computer-on-a-chip embedded systems. They usually have multiple I/O ports, RAM, ROM & flash memory, a microprocessor, and A/D converters [10]. The researchers preferred to use Arduino Uno because its functions are readily available on the board albeit the availability of other powerful and cheaper microcontrollers [11].

For the sensor communication, a long range transceiver on an Arduino Shield form factor was used. LoRa RFM95 Shield allows users to send data and reach long ranges at low-data rates. The transceiver can go from 2 kilometers line of sight using regular antennas, or up to 20 kilometers of range with beam antennas. LoRa Shield has high interference immunity which minimizes current consumption [12].

Lastly, QGIS was used to map out the traffic flow of Cebu City, specifically in the Banilad area. QGIS is an open-source mapping application that is free of charge. The data gathered from the sensors were interpreted and presented using the geographic information system mentioned above.

The goal of the study is to help the traffic management organizations in mitigating traffic congestion by developing a system that will illustrate the traffic flow situation in Cebu City on a mapping application through the use of ultrasonic sensors for gathering traffic flow data.

The study has the following objectives:

- Develop a method of estimating a vehicle speed using a single, stationary ultrasonic sensor
- Illustrate the traffic flow of a given road sector by using geographic information system

The system has the following scope and limitations:

- The system only maps traffic flow based on the gathered data from sensors which will be installed at an identified sector of the road
- The system is only applicable for a one-directional lane. The system can be scaled with one sensor per lane
- The system does not consider counterflowing vehicles.
- The system does not consider motorcycles and other two-wheeled vehicles.
- The system does not receive speed data at the same time.
- The traffic flow is displayed on the geographic information system.
- The mapping application does not display real-time data.

II. METHODOLOGY

A. *Study Area and Input Data*

The system's point of convergence was the skywalk near Banilad Elementary School with the selected sectors of road: Banilad Town Center to Gate 1 of University of San Carlos - Technological Center and vice versa. To calculate the speed of the vehicle, the following were considered as input data:

- length of the vehicle
- height of the vehicle
- time it took the vehicle to pass underneath the sensor

To illustrate the traffic flow on the mapping application, the calculated speed was used as an input dataset. To calculate the speed, the length of the vehicle is divided by the time a vehicle crosses the sensor. The speed of the vehicle was employed to display different color schemes of traffic flow by averaging. The average speed was color coded according to the traffic conditions. Colors such as red, orange, yellow, light green, and green were used to signify the speed of traffic on the road.

B. *Conceptual Framework*

The main system diagram as shown in Figure 1 displays the concept of the system. The transmitters, labeled as A and B, consist of a microcontroller, an ultrasonic sensor, a communication shield, and a 9V battery. Transmitter A was placed above the inner lane going south while Transmitter B was placed above the inner lane going north. When the sensors detected a vehicle, the transmitters sent data to the receiver. The receiver consists of a microcontroller and a communication shield. Once data was received, the geographic information system reflected the received data and showed the current traffic situation.

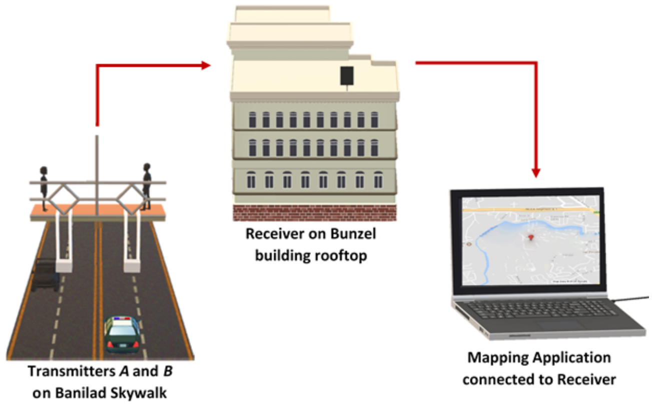


Figure 1. System Diagram

C. *Transmitter Prototype*

The ultrasonic sensor attached to the transmitter emitted sound waves which vehicles reflected. The data that came from the sensor was sent to the microcontroller. When data was received, the microcontroller computed the speed of the vehicle and then sent the computed data to the receiver. Shown in Figure 2 is the prototype and connections inside of a transmitter on the left and the actual device on the right.

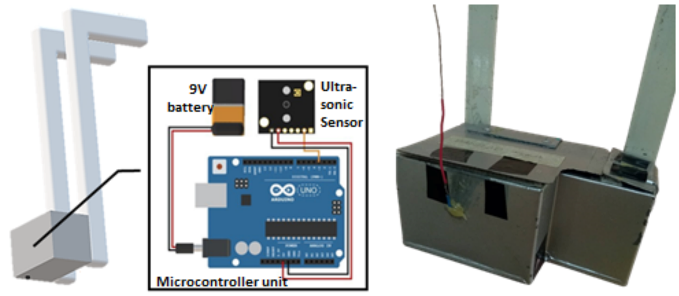


Figure 2. Components of Transmitter

a. Ultrasonic Sensor

The transmitter is equipped with MB1010 LV-MaxSonar-EZ1 ultrasonic sensor (see Appendix A). The researchers chose this type of ultrasonic sensor due to its range, which is 6 inches to 254 inches, 20Hz read rate, and various output options: pulse-width, analog voltage, and RS232 serial [13]. The ultrasonic sensor emits sound waves waiting for a reflected wave indicating that a vehicle is within range. The ultrasonic sensor keeps on emitting sound waves and sends data to the microcontroller whenever a wave bounces back. Once a wave bounced back, the data received will be calculated to identify the speed of the vehicle.

b. Microcontroller Unit

The speed (kilometers per hour) for the vehicles that passed underneath the skywalk was computed from the distance data from the ultrasonic sensor via a PWM (Pulse Width Modulation) port. The data was taken by the Arduino and was converted into inches. From there, a function first determined if a vehicle had been detected or not, so if true, started a timer. Once the timer started, the function classified a vehicle to either a sedan, SUV, or truck based on the distance data gathered as vehicle types have different average heights[14]. With Figure 3 as the criteria for determining vehicle length using the distance data gathered and the vehicle's classification, distance used in the speed equation (see Equation 1) can be determined. Vehicles that have irregular dimensions are still classified by its height despite the length being different than that of the actual vehicle, which might make calculations of its speed inaccurate. In regards to jeepneys, most jeepneys that run around Cebu nowadays are categorized as 3rd-generation jeepneys which means they are either modified Isuzu Elfs which are categorized as trucks, or modified multicabs such as the Suzuki Carry (8th Gen) which are categorized as SUVs[15]. When the vehicle is no longer detected, the timer stopped and used the time it measured for calculating the vehicle's speed.

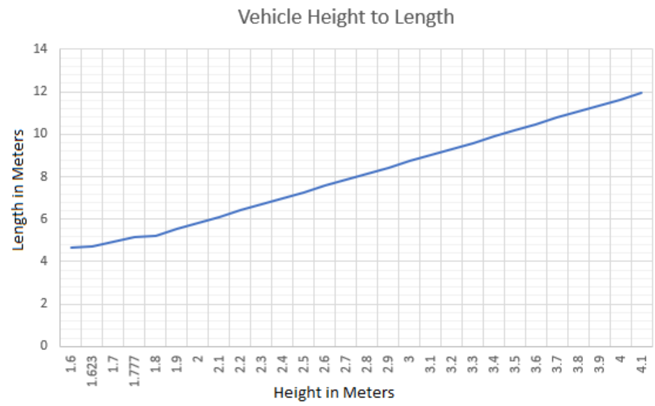


Figure 3. Vehicle Height to Length

$$s = \frac{d}{t} \tag{1}$$

where:

- ***s*** is the speed of the vehicle
- ***d*** is the length of the vehicle
- ***t*** is the time measured from the timer

The function was looped until the vehicle was no longer detected, thus, the timer was stopped. The values were converted so that the resulting speed data were in kilometers per hour. The timer's data, and vehicle length were then used to compute the speed. The computed speed was then put into a packet with an ID, to identify which transmitter sent the data. The packet was then sent to the LoRa Shield to be sent over LoRa to the receiver prototype.

D. *Receiver Prototype*

The researchers opted to use LoRa since it has good receiver sensitivity and low bit error rate from inexpensive chips. Thus, low-data rate applications can get much longer range using LoRa rather than using other comparably priced radio technologies [16]. It is ideal for providing intermittent low data rate connectivity over significant distances. The radio interface has been designed to enable extremely low signal levels to be received, and as a result even low power transmissions can be received at significant ranges [17].

After the speed was computed, the data were transmitted to the central receiver. The speed data was sent over the wireless network which is LoRa and was segregated into the different flow sections. Since the ultrasonic sensor and the transmitter alone cannot both read and transmit the data from the ultrasonic sensor all the way to the centralized receiver, a microcontroller is needed in the receiver prototype. The microcontroller integrated the sensor and the communication shield. After the data were received from the transmitter, data were then distributed to the mapping application for interpretation of traffic flow data through a data acquisition application. The receiver prototype (top) as well as the actual mounting of receiver device (bottom) are shown in Figure 4.

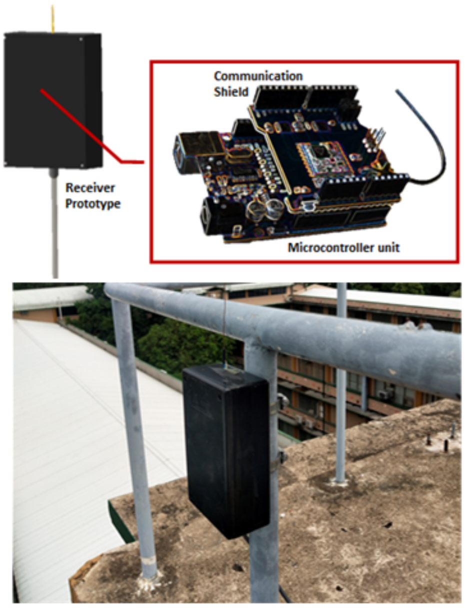


Figure 4. Components of Receiver

E. *Mapping Application*

The data collected from the receiver was interpreted and displayed on the QGIS mapping application (as shown in Figure 5). QGIS was used in this system due to the following factors [18]:

- QGIS is fast compared to other mapping software
- QGIS is user-friendly
- QGIS is compatible with Windows, Linux, Android, and Mac OS for easy installation
- QGIS is free and less to maintain

With this, QGIS is definitely the ideal software to use for traffic mapping applications especially for the target users which are the traffic management organizations.

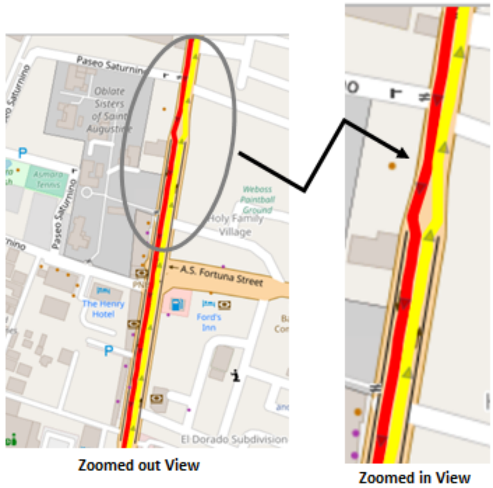


Figure 5. Actual Traffic Flow Layout

The speed data were uploaded to the mapping application from the receiver and updated its vector map through the gathered values. The accumulated data were classified as real number values which can be converted to any desired data type. Values of longitude and latitude were included to determine which transmitter the data belonged to.

F. *Testing*

a. *Test Environment*

The system's focal point is the skywalk near Banilad Elementary School. The road from Banilad Town Center to Gate 1 of University of San Carlos - Technological Center and vice versa was selected as the identified sector which begins and ends the traffic flow illustration. The system targeted on becoming a basis in decision-making for traffic management organizations to bring into service.

For the system testing, the tests were conducted on the actual skywalk for transmitters A and B, on the rooftop of Bunzel building for the central receiver, and on the 4th floor hallway of the same building for the mapping application. The central receiver is connected to the mapping application through a remote wired connection.

b. *System Testing*

Unit tests were performed in each module: transmitter, receiver and mapping application. The researchers used the white box testing in order to detect defects of the internal structure of each module. The unit testing was then followed by the integration testing and lastly, the overall system testing.

1. *Unit Testing*

The unit testing was accomplished by validating each unit performed as it was designed. A series of tests were conducted on the sensor module, network module and the mapping module.

i. *Sensor Module:* The components of the sensor module were tested through the Arduino IDE Serial Monitor tool. The tool printed the distance from the sensor as well as the flag if an object was detected. If an object has been detected, the tool prints "Something Detected" and if the timer hasn't been started yet, it prints "Timer Reset". The tool kept on printing the distance, flag and the affirmation of an object being detected until the object was no longer detected. When the latter happens, the tool prints "Stop Detecting" and then prints the time elapsed, speed, and packet.

ii. *Network Module:* The network module was tested by using the Arduino IDE Serial Monitor tool. The tool printed "CLEARDATA" and "RESETTIMER" when the data acquisition application cleared the data and reset the internal timer. It also printed "LABEL, Date, Time, Speed A (kmph), Speed B (kmph)" which are the head labels for the data file. After data was received, it printed "DATA, DATA, TIME," and then the received data.

iii. *Mapping Module:* The mapping application was tested by encoding random speed data in the file where data was stored. The script that handled the color transition of the road was then implemented and it displayed the color scheme according to the flow of traffic after the script was executed.

2. *Integration Testing*

The sensor, network and mapping modules were combined as a group for the integration testing. The researchers employed the Big Bang approach to integration testing where the interactions of each module were tested in one setting.

G. *System Verification*

The researchers conducted a series of tests during implementation considering the two main parts of the system: Moving Vehicle Speed Identification and Traffic Flow Illustration.

a. Moving Vehicle Speed Identification

Each vehicle that passed underneath the transmitter prototype was classified as either a sedan, SUV, or truck, depending on the height of the vehicle. The class the vehicle belonged to has its own corresponding average vehicle length. This average vehicle length is what is used for the distance travelled in computing the resulting speed. Time was measured starting from when the vehicle started passing underneath the sensor, until it was no longer underneath the sensor.

b. Traffic Flow Illustration

The system in displaying the data reflected the flow of traffic in the mapping application within the system's focal point. It is verified through checking the speed of the car with a speedometer to see if the flow of traffic is in line with the mapping application. The researchers also verified the system's traffic flow data by comparing it to Google Maps.

III. RESULTS AND DISCUSSION

A. *Data Results*

The data gathered by the researchers were separated into two parts: day-shift data and mid-shift data. Day-shift data is composed of speed data from 10AM to 12NN. On the contrary, mid-shift data started from 4PM to 6PM. The researchers decided to divide the gathering of data into two in order to differentiate the traffic flow using the color schemes. Data gathering was conducted on a total of four days consisting of one weekend day and three weekdays. Traffic flow data is represented with colors on each lane. When average traffic flow is 10 kph or below, the color red is shown. Meanwhile, orange represents average data less than or equal to 20 kph but greater than 10 kph. The color yellow represents an average less than or equal to 30 kph but greater than 20kph. Light green represents an average less than or equal to 40 kph but greater than 30 kph and, lastly, green represents averages that are greater than 40 kph.

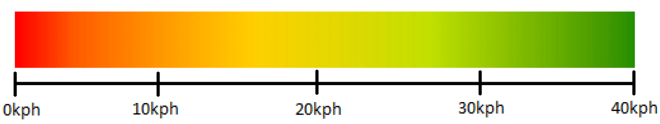


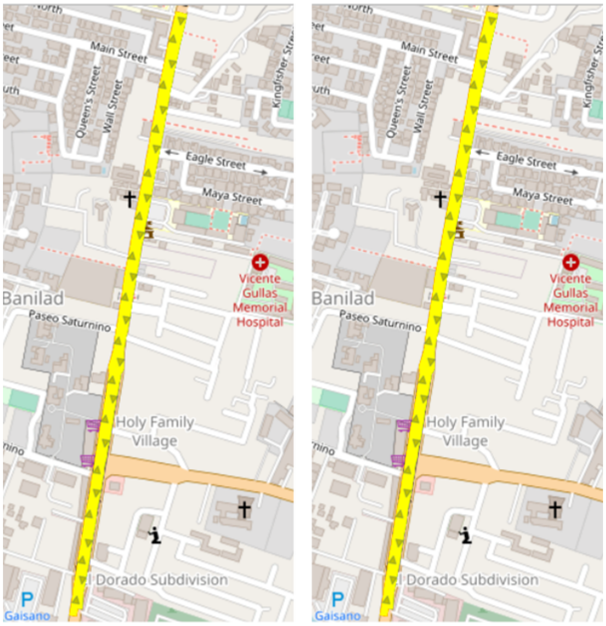
Figure 6. Color Spectrum of Traffic Flow Speed

A sample speed datasheet is shown in Table 1. In the first column, time is presented at the moment it received data. The second and third columns are the detected speed of vehicles. Speed A represents the lane going south while Speed B represents the lane going north. No two speeds are recorded at the same time since the transmitter will only send the first data it receives to the receiver.

Time	Speed A (kmph)	Speed B (kmph)
10:59:58		50.58
11:00:20		46.23
11:00:39	42.4	

11:00:40	42.17	

Table 1. Sample Speed Datasheet

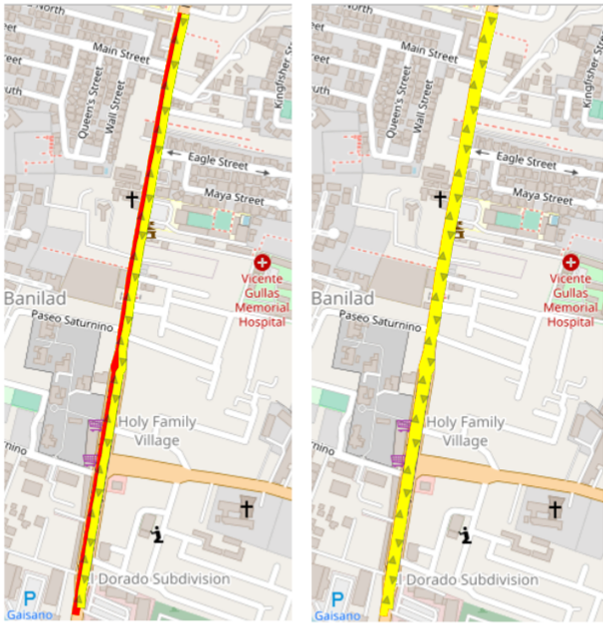


(a) (b)

Figure 7. Friday Testing Results

The first system testing was conducted on a Friday. As shown in Figure 7, both day-shift (a) and mid-shift (b) experienced light to moderate traffic flow on lanes going southbound and northbound.

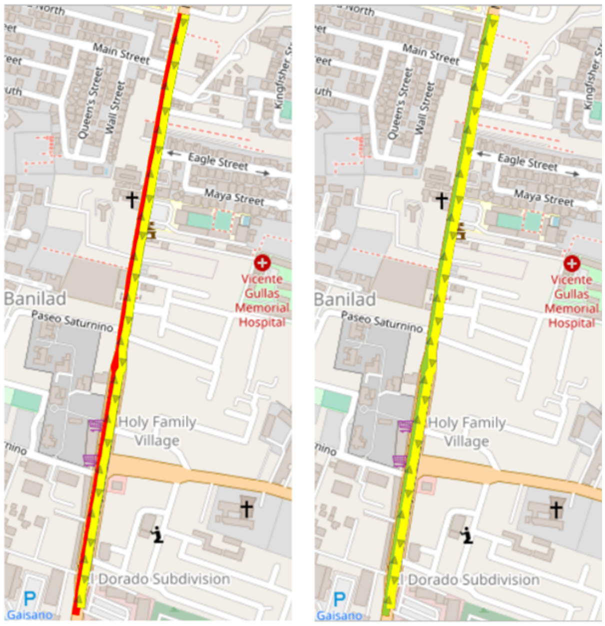
The second testing was conducted on the next day, Saturday. As shown in Figure 8, the traffic flow was heavy on the southbound lane during the day-shift (a) but eased up to light to moderate traffic flow in the mid-shift (b). The northbound lane however was constant in having light to moderate traffic conditions on day-shift and on mid-shift.



(a) (b)

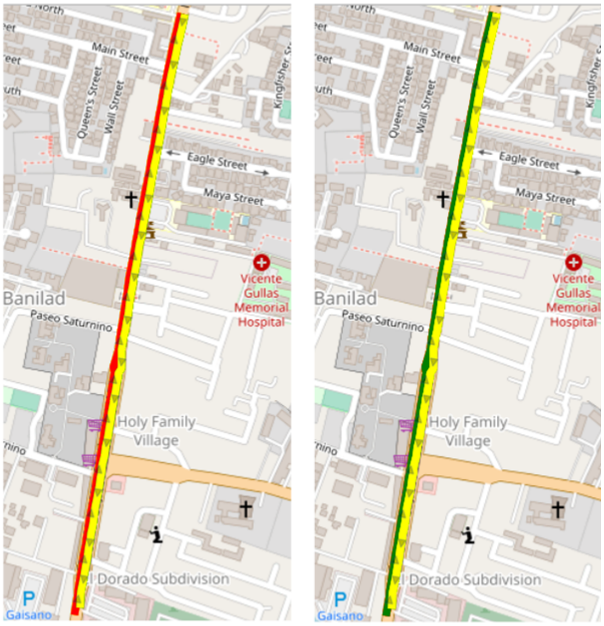
Figure 8. Saturday Testing Results

Shown in Figure 9 is the traffic flow situation on Monday. The lane going southbound experienced heavy traffic delays on day-shift (a) and no to light traffic flow on mid-shift (b). Meanwhile, the lane going north still experienced light to moderate traffic flow on both day-shift and mid-shift.



(a) (b)

Figure 9. Monday Testing Results



(a) (b)

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Figure 10. Tuesday Testing Results

On Tuesday, the southbound lane experienced heavy traffic conditions on day-shift (a) but eased up to no traffic flow on mid-shift (b) as shown in Figure 10. The northbound lane, being consistent, still experienced light to moderate traffic flow on both day-shift and mid-shift. July 16 was the last day of system testing.

Based on the results gathered by the researchers, Saturday, Monday and Tuesday had the most traffic delays especially on day-shift while Friday had the lesser amount of traffic among the four days of system testing with light to moderate flow of traffic. The traffic usually builds up on the lane going south since there is an intersection underneath the flyover which may cause delays. On the contrary, the lane going north has no crossings that may affect the flow of traffic on the road. The junction of A.S. Fortuna and Gov. M. Cuenco Avenue link has become a loading and unloading station of jeepneys turning to A.S. Fortuna road and jeepneys bound to south whenever a traffic enforcer is not around, stalling the vehicles behind them and dominating both lanes.

B. Data Interpretation

During data gathering, the researchers observed that there are vehicles that have irregular dimensions due to vehicle attachments or things such as cargo. But these vehicles were scarce during the four days of data gathering. Based on a 5 minute video recording of the actual data gathering, a total of 57 vehicles were detected and only 1 showed modified/altered length which is shown on Figure 11. This makes it only 1.76% of the total vehicles recorded during the 5 minute period and can be neglected because this data will be averaged with other vehicle speed data to determine average traffic flow speed for the mapping application.

Figure 11. Vehicle with irregular length due to cargo

Figures 12 to 15 present the number of vehicles that both transmitters detected during the system testing. The lane going south on mid-shift Friday has the lowest amount of vehicles detected while the highest amount of vehicles detected was recorded on Tuesday day-shift on the northbound lane. When there is traffic congestion, vehicles tend to move slower than usual. The longer the time it took the vehicle to move out from the vicinity of the ultrasonic sensor, the lesser the amount of vehicles to be detected. Time, which is a key component in computing the speed of the vehicle, is measured starting at the moment the sensor has detected an object until it is no longer detected. During the system testing, it was implied that the volume of vehicles does not equate to traffic flow. In spite of the fact that traffic jams are caused by the increased number of vehicles present at the same time, the detection of the ultrasonic sensor relies on the vehicles going through the sensor's field of detection.

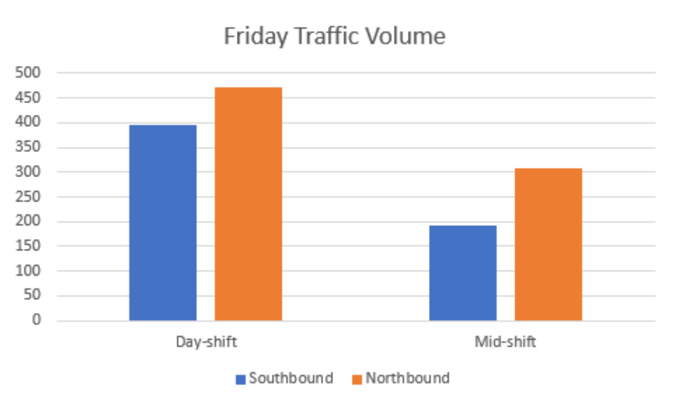

Figure 12. Friday Traffic Volume

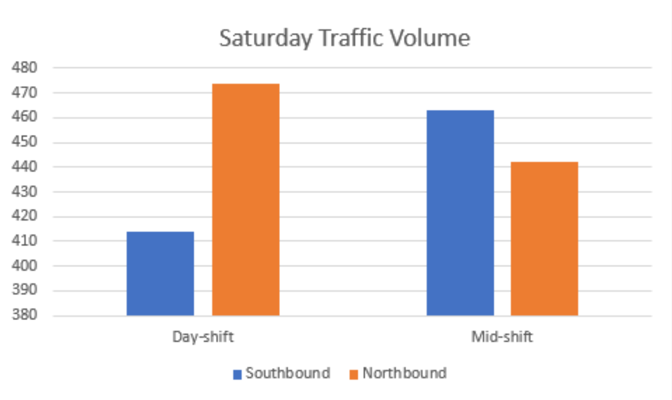

Figure 13. Saturday Traffic Volume

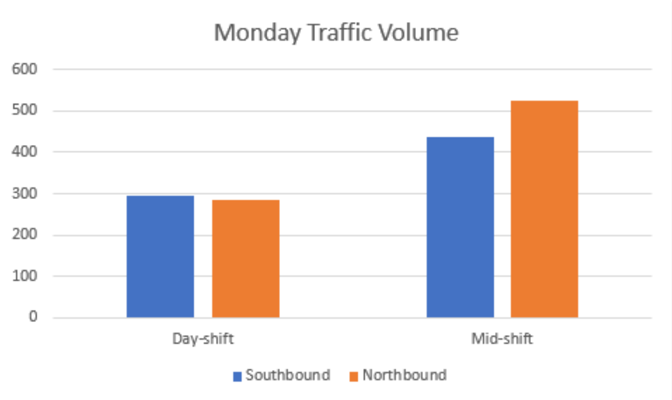

Figure 14. Monday Traffic Volume

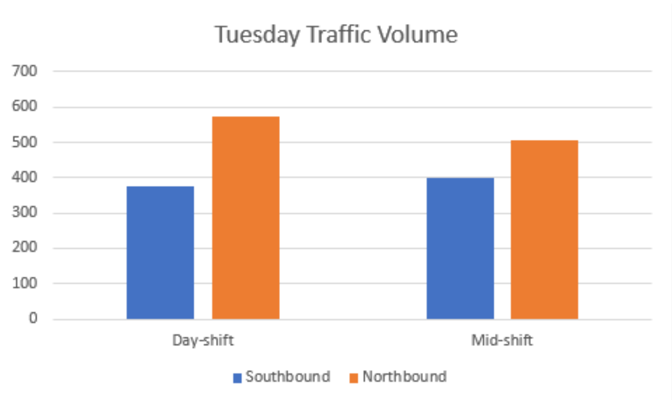

Figure 15. Tuesday Traffic Volume

The following graphs show average speed from the different testing days. Friday southbound mid-shift having the lowest amount of vehicles correlates to its average speed being low on the same lane on mid-shift. This is also similar to Tuesday northbound day-shift where it had the highest number of vehicles and also had a high traffic flow average speed.

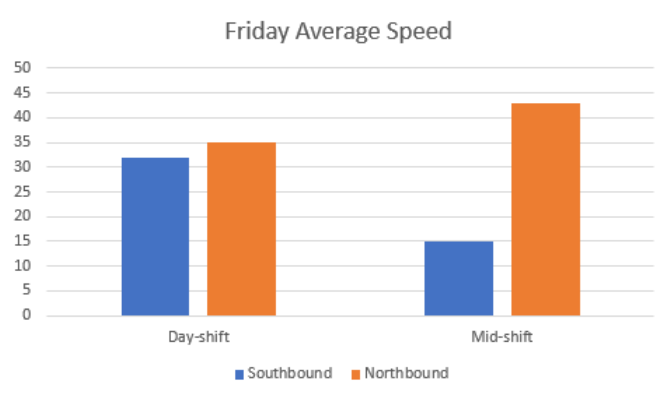

Figure 16. Friday Average Speed

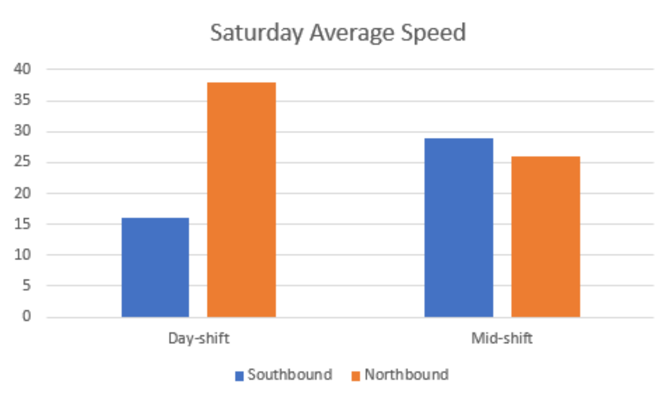

Figure 17. Saturday Average Speed

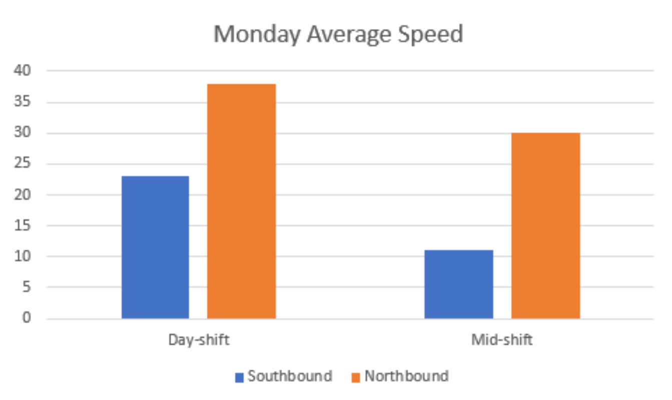

Figure 18. Monday Average Speed

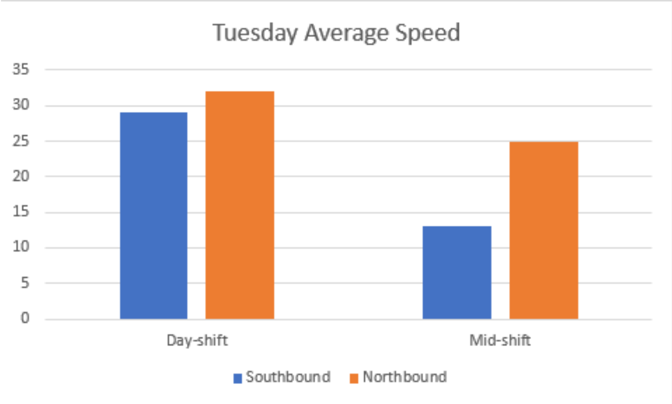

Figure 19. Tuesday Average Speed

IV. CONCLUSION AND RECOMMENDATION

The transmitter units that were made as non-intrusive to the road as possible were able to detect vehicles passing and calculate their speeds which are then sent to the receiver. From the data gathered and analyzed, the vehicle speeds showed low values when traffic was slow and high values when traffic was fast therefore satisfying the first objective of estimating vehicle speed using an ultrasonic sensor.

The system was then able to map out the traffic flow of the road going to and from Banilad Town Center to Gate 1 of the University of San Carlos - Technological Center using the vehicle speeds gathered by the transmitter units. The mapping application showed color transition of the road with the data matching the color scheme of the script used therefore achieving the second objective of illustrating traffic flow of a given road sector by using a geographic information system.

Compared to crowdsourced traffic mapping, this study does not intrude on people's privacy as the system directly gets its data from roads themselves and not from tracking people. Users would be ensured that the data gathered directly comes from vehicles ensuring them that there is no false data gathered. The achievement of the two objectives together with the impact of the study inferred that traffic management organizations will be able to use the system as a basis for their decision making.

Based on the feedback of the tests that were conducted, the researchers made the following recommendations:

a. More vehicle classes

For the system, the researchers only used three vehicle classifications being sedans, SUVs, and trucks. There are a lot of different vehicle classes that could be added to further increase the accuracy of the speed estimation. This also includes vehicles that have modified/altered lengths due to cargo or various body attachments.

b. Ambient temperature readings

The researchers recommend adding an ambient temperature thermometer to the system since an ultrasonic sensor was used. Ambient temperature affects the speed of which sound travels which would also affect the distance data gathered.

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