Development of an Integrated Traffic Monitoring System with Self-Sustained Power Management Plan using Solar Energy

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***Abstract* – This project study aims to address the inconsistent and imprecise presentation of traffic data analytics of the existing traffic monitoring systems and applications. In addition, this study intends to implement the concept renewable energy in designing Power Management Systems (PMS) for Internet-of-Things (IoT)-enabled systems for Smart City application. To address the problems, the researchers designed and developed an integrated traffic monitoring system that can monitor the real-time traffic condition of various areas, as well implement the use of renewable energy. Two sub-systems mainly constitute the system, the Data-gathering sub-system, composed of Closed-Circuit Television (CCTV) Camera, Digital Humidity and Temperature Sensor, Flood Level Monitoring Device, and Microcomputer; and the Power Management Sub-system (PMS), composed of Energy Storing Device, Battery Monitoring System (BMS) and Solar Energy Capturing Device. Alongside the primary sub-systems, a Communication Sub-system composed of Wi-Fi-enabled communicating device backed up by a Long-Range Wireless Area Network (LORAWAN) device is interfaced to enable the communication of each device to the brain of the system and to connect the system to the Internet. The system is housed in a weather-proof box, and then installed to the road-side lampposts. This implementation allowed the system to efficiently monitor the variables affecting the traffic condition of different areas. The system was able to capture images from the target subjects, record humidity and temperature values with high accuracy, and provide enough power to keep the system in 24-hour operation. Through this project, drivers and commuters can monitor the current traffic situation in real-time, help the Local Government Units (LGUs) lessen the time wasted in responding to emergencies and concerns in the road, and maximize the use of renewable energy.**

***Keywords* – Smart City, Internet-of-Things, Traffic Monitoring System, Solar Energy**

I. Introduction

Transportation plays a key role in the continuous development of our living state. Time progresses as the technological development of the various transportation modes, from the invention of bicycles to the mass production of various motorized vehicles. However, this development comes with negative effects that becomes hinderance in societal development if not handled properly. Traffic congestion is considered as one of the main problems that all countries are trying to solve. Several factors contribute to the growing problem of traffic congestion, such as weather conditions, state of infrastructure development, population density, vehicle density, to name a few. Locally, this problem has a big impact on the economic aspect. Metro Manila loses 2.1 Billion Pesos a day in 2012 and jumped to 3.5 Billion Pesos a day in 2017 [1]. In 2015, Metro Manila was asserted as the 'worst traffic in Southeast Asia', considering its population and vehicular density [2]. It also affects the physiological and psychological states of individuals as people experiencing heavy traffic congestions are bounded to peak levels of stress [3]. Other people tend to elicit anger on top of stress, often leads to aggressiveness and temper issues.

The government have been taking some steps to address this problem, such as the Unified Vehicular Volume Reduction Program (UVVRP) which was proven to be effective in the early years of its implementation but its effectiveness diminishes as years pass by [4], truck bans in certain roads, utilization of social media such as Twitter, Facebook, etc. to continuously update the citizens on traffic conditions of the major roads. Private entities such as Google and Waze development navigation applications (Google Maps, Waze, etc.) to aid the people in traveling, however, these applications were found to be unreliable at times due to its dependence on GPS signal and internet connection, leading to location inaccuracies and time calculation inconsistencies. In highly urbanized metropolitan areas around the globe, the concept of Smart City is being adapted and utilized as a countermeasure for traffic congestions.

The Smart City concept is defined as the utilization of various intelligent sensors deployed on the road or field, interconnected into a network, commonly via Internet-of-Things (IoT), where the data collected by the sensors are sent to a central server that processes this raw data into useful information. Smart City gives a promising future not only in the field of traffic management, but as well to the inclusive growth of one nation.

This study aimed to incorporate and implement the advanced technology of traffic monitoring and management system to the local scene, paving the way of Smart City technology to be introduced to the local setup and inspiring the government and the private sector for its implementation from small-scale to large-scale deployment. This study shows the development of an integrated traffic monitoring system comprised of smart sensors, wireless network technologies, and green technology.

II. Methodology

This study aims to develop an integrated traffic monitoring system with self-sustained power management plan using Solar Energy with the following objectives:

1. To develop an integrated system of traffic monitoring sensors and devices in a form of a lamppost;
2. To determine and set a standard lamppost capable of supporting the system's over-all functionality;
3. To create and materialize a self-sustained power management plan using Solar Energy to support the integrated system; and
4. To test and ensure the efficiency of the system upon deployment.

The proponents adapted the concept of evolutionary prototyping to develop this study.

A. *Development of the Integrated System*

Gathering of System Materials, Devices & Equipment

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Testing of Individual Functionality and Connectivity

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Assembly of the Integrated System

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Deployment and System Installation

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System Configuration and Functionality Checking

Fig. 1. Integrated System Development Diagram

Figure 1 shows the process of the development of integrated system. The system is primarily divided into 3 sub-systems, the input sensors system, the microcomputer system, the computer-network system, and the power management system. The input sensors system is composed of the IP-Based CCTV Camera, the DHT-22 Sensor, and the Flood Monitoring Sensor with Float Switches serving as the input sensor, processed by an XOR logic circuit. The microcomputer system is composed of the Raspberry Pi, the Arduino, and a network router serving as the communication gateway between the input sensors and the microprocessors. The power management system will be discussed in the later part of this chapter. The CCTVs send data via File Transfer Protocol (FTP), while the DHT-22 and Flood Monitoring Sensors are interfaced to the Arduino that communicates with the Raspberry Pi via Secure Shell Protocol (SSH). The data collected are stored in a local directory, set with a cronjob of auto-deletion after 2 days to avoid shortage in storage. The stored data is as well ready to be sent to the central server using Wi-Fi and the LORAWAN as backup.

Figure 2. Deployment Map Plan

The integrated system is then mounted to a lamppost, in coordination with the local government and the barangay office. The CCTVs are installed strategically to cover the incoming traffic from the assigned traffic route and direction. After installing the integrated system, the final configuration and checking will take place. This is to ensure that the system will be functioning according to its expected behavior and that the proper and correct data will be gathered.

B. Development of the Power Management System

Determining of the Operational Requirements

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Gathering of Materials

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Assembly and Integration to the Integrated System

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Efficiency Checking

Fig. 3. Power Management System Development Plan

The third figure shows the development of the power management system (PMS). This system is composed of three (3) parts: (1) energy storage, (2) energy controller, and (3) energy harvester.

Solar Energy is considered to be one of the most popular renewable energy sources. The Earth receives approximately 4 Million Exajoules ($4x10^8$ J) of solar power annually, making it a promising energy source most especially in countries near the equator, like the Philippines [5]. This study utilizes Solar Energy as the main source of energy for power supplication of the system, in an Off-Grid setup.

Lithium Ion (Li-ion) batteries are the most suitable storage device for Solar Energy application. This is due that Li-ion batteries have longer lifespan and higher energy & power densities as compared to other types of batteries [6]. Li-ion batteries are also popular in the consumer electronics industry. In this study, a Li-ion battery pack is devised to store the harvested Solar Energy. The system operates mainly in 12V; thus, the battery pack is rated in the same rating and is connected in series-parallel connection to increase its capacity.

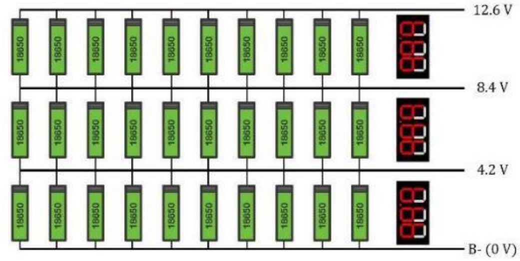

Fig. 4. The Li-ion Battery Back Wiring Diagram

A monocrystalline solar panel shall be utilized in this study to harvest the solar energy. The solar panel and the battery pack is connected to a 3S 50A Battery Management System (BMS). This BMS shall control the flow of energy in the PMS to ensure that no unwanted current will flow in the system and to stabilize the current flow in the system since fluctuating current may damage the devices in the system. A 12VDC-5VDC converter completes the PMS since the Raspberry Pi and the Arduino is operating at 5VDC.

Device	Power Consumption
RLC-410 IP Camera (3 pcs)	< 10W * 3 = (Max) 30W
Arduino Uno	0.4W
Raspberry Pi	2W
TL-MR3220 Router	7.65W
Total Power Consumption	**~40W**

Table 1. System Power Consumption Table

Table 1 shows the total power consumption of the integrated system that the PMS will provide. Also, the system operates in 24/7 mode.

III. Results and Discussion

The study is evaluated on the materialization & deployment of the integrated system, the input data from the sensors, and the efficiency of the PMS.

A. *Materialization & Deployment of the Integrated System*

Fig. 5. The Integrated System

Figure 5 shows the developed prototype of the integrated system. The computer system and the PMS enclosed in a weatherproof box are shown.

Figure 6. CCTV Camera along Ayala Blvd-Eastbound

Figure 7. CCTV Camera along Ayala Blvd-Westbound

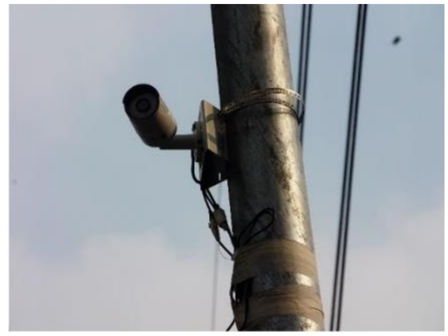

Figure 8. CCTV Camera along San Marcelino St-Southbound

Figure 9. The Integrated System mounted at a lamppost

Figure 10. The Solar Panel Mounted at a lamppost

Figures 6 to 10 shows the installed integrated system into the target area of deployment.

Figure 11. Sample data captured from the CCTV Cameras in an interval

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0, 0, Humidity: 81.60 %, Temp: 30.20 Cels
0, Humidity: 81.40 %, Temp: 30.20 Celsius
0, Humidity: 81.40 %, Temp: 30.20 Celsius
0, Humidity: 80.70 %, Temp: 30.20 Celsius
0, Humidity: 81.20 %, Temp: 30.20 Celsius
0, Humidity: 81.20 %, Temp: 30.20 Celsius
0, Humidity: 81.10 %, Temp: 30.20 Celsius
0, Humidity: 81.10 %, Temp: 30.20 Celsius
0, Humidity: 81.30 %, Temp: 30.20 Celsius
0, Humidity: 81.40 %, Temp: 30.20 Celsius
0, Humidity: 81.70 %, Temp: 30.30 Celsius
0, Humidity: 81.30 %, Temp: 30.20 Celsius
0, Humidity: 81.60 %, Temp: 30.30 Celsius
0, Humidity: 81.60 %, Temp: 30.30 Celsius
0, Humidity: 81.40 %, Temp: 30.30 Celsius
0, Humidity: 82.00 %, Temp: 30.30 Celsius
0, Humidity: 81.60 %, Temp: 30.30 Celsius
0, Humidity: 81.20 %, Temp: 30.30 Celsius
0, Humidity: 81.60 %, Temp: 30.30 Celsius
0, Humidity: 81.40 %, Temp: 30.30 Celsius
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Figure 12. Sample Data from the DHT-22 and the Flood Monitoring Sensor

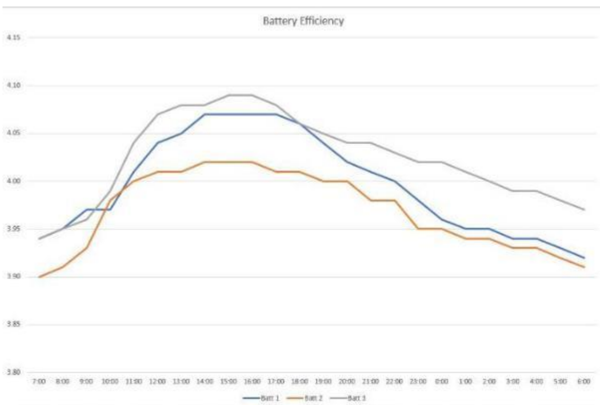

Figure 13. Average Battery Level

The graph shows the average battery levels of the PMS upon charge and discharge operation. In day time operation, it can be seen that the voltage level rises as the solar panel charges the battery pack. In noon time, a big jump charge can be seen since the absorption of solar energy is at its peak. As night time approaches, the PMS shifts into discharge mode and slowly, the battery level diminishes, further slowing down during midnight since the computer processes less data due to lesser road activities in midnight.

IV. Conclusion & Recommendations

The development of the integrated traffic monitoring system was successfully done. The system has responded based on its expected behavior, and it was able to capture appropriate data from the image and telemetric sensors. The power management system was also successfully devised to efficiently support the operation of the integrated system. The utilization of Solar Energy on the PMS is also successful based on the voltage levels presented. Over-all, the integrated system was effective and efficient to implement on traffic monitoring and surveillance.

For further improvement of the study, the following recommendations may be done:

a. Use of smart sensors (weather, GPS, etc.)
b. Redesign a smaller system with 1:1 camera implementation.
c. Use of other renewable energy source (piezo, wind, etc.) based on the available sources in the area of deployment.
d. Utilization of Polymer Lithium Ion (PLi-ion) Battery for more efficient energy storage and supplication.
e. Use of smart battery health monitoring device

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