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. The system generates to types of data, the image data captured by Closed-Circuit Television (CCTV) Camera; and the telemetric data captured by the Digital Humidity and Temperature (DHT) Sensor and the Flood Level Monitoring Circuit interfaced to a Microcontroller. These data are stored in a local directory found in the Microcomputer, where the Communication System Unit of the system is connected to transmit the stored data via Wi-Fi, backed up by Long Range Wireless Area Network (LORAWAN). The system is powered by a Power Management System (PMS) in the form of an Off-grid Solar Power System where the Solar Energy captured by the energy-harvesting device connected to a Battery Monitoring System (BMS) is stored in an Energy Storage Device. 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

Smart city gives a promising future to every nation in the world. Defined as an urbanized area that utilizes electronic sensors to collect data communicating via Internet-of-Things (IoT), Smart City technology opens vast ideas of futuristic development for area monitoring, traffic management, and other related urban planning concepts. Going into the grounds, our daily living heavily relies on massive transportation to execute our daily activities. And with the start of the 4th Industrial Revolution, digital technology comes in as co-key player in the continuous progress of our modern lives.

Transportation is defined as the movement of people, goods, and services from one place to another. With the start of mass production of motorized vehicles in the mid 1900's, it has become the main means of transportation. However, the infrastructure development in developing nations has not been able to keep up with the fast-growing demand of motorized vehicles. Looking at the local situation, the number of vehicles has outnumbered the number of passable roads, resulting to heavy traffic congestions that dubbed Metro Manila as the 'worst traffic in SEA region' [1]. Economically, the nation's capital loses about 3.5 Billion Pesos a day in 2017[2]. Psychological and physiological distress also became a major negative effect of heavy traffic congestions to drivers and commuters [3].

Various highly urbanized areas around the world has effectively addressed the traffic crisis that they have experienced. Among the measures that these nations have taken, the implementation of smart city stands out. The city of Dubai in United Arab Emirates has been observed with the best practices and policies in connection to their implementation of smart city through their Smart Tourism Dynamic Responsive System (STDRS) [4]. The City of Dublin in Ireland stresses another perspective of smart city in being 'citizen-centric' and emphasizing the role of their smart-citizens through the tool called 'Scaffold of Smart Citizen Participation' [5].

This study aims to incorporate the concept of smart city by devising an integrated traffic monitoring system. This integrated system is an integration of smart sensors capable of monitoring real-time traffic conditions via imagery and weather condition data. This study also stresses the importance of green technology via implementation of a self-sustained power management system that relies on renewable energy in the form of Solar Power.

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

The integrated traffic monitoring system is composed of different devices that captures and stores data in a local storage, making it ready for transmission to the central data server. An IP-based CCTV Camera shall be used for capturing images. For this study, the RLC-410 IP-PoE camera shall be integrated to the system.

Figure 1. RLC-410 IP-PoE Camera

Temperature, Humidity Percentage, and Flood Level are the weather parameters that this study shall be using. The DHT-22 Sensor shall be used for recording temperature and humidity levels, while a Flood Level Monitoring System (FLMS) driven by an XOR gate with float switch as its input shall be used to record flood levels.

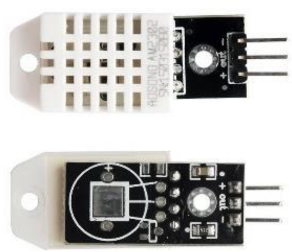

Figure 2. DHT-22 Sensor

Figure 3. Analog Float Switch

The DHT-22 and Flood Level Monitoring sensors are interfaced to a microcontroller to process the electrical signals into a readable data. This study utilizes the Arduino Uno R3.

Figure 4. Arduino Uno R3

The CCTV Camera communicates with the system via a network router, an advantage of IP cameras over conventional CCTV cameras, connected via Local Area Network (LAN). A microcomputer serves as the brain of the system, which stores and processes the data captured. For this study, the Raspberry Pi 3B+ is used.

Figure 5. Raspberry Pi 3B+

The CCTV Cameras are communicating with the microcomputer via File Transfer Protocol (FTP) over the local network and the microcontroller communicates with the microcomputer via Serial Communication Line and stores the processed data via Secure Shell Protocol (SSH). An autodeletion cronjob for the stored data is set to the microcomputer to avoid crowding of storage with unnecessary files.

Figure 6. Software used in project development

B. Development of the Power Management System

This study utilizes Solar Power to support the system's functionality. The Off-grid Solar Power System setup is implemented as the Power Management System (PMS).

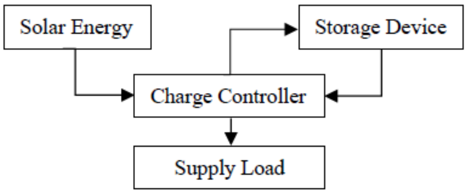

Figure 7. Off-Grid System Block Diagram

Unlike Hybrid systems, Off-Grid or Standalone Solar Power System setup does not have support from conventional power sources, as this solely rely on harvested Solar energy. This setup operates on two modes, the supply-charge mode that happens in daytime and the supply-discharge mode that occurs in nighttime or when the received solar energy is insufficient. The Earth receives approximately 4 Million Exajoules (4x108 J) of solar power annually, making it a promising energy source most especially in countries near the equator, like the Philippines [6].

Device	Power Consumption
RLC-410 IP Camera (3 pcs)	< 10 W * 3 = (Max) 30 W
Arduino Uno	0.4 W
Raspberry Pi	2 W
TL-MR3220 Router	7.65 W
Total Power Consumption	**40.05 W**

Table 1. Rated power consumption of devices

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 [7]. Harvested energy is stored in a Lithium-ion Battery Pack, made up of 18650 4.2V 2600mAh Lithium-ion batteries connected in series-parallel to create a 12V-rated battery pack. To materialize the battery pack, computations on its capacity rating and the number of batteries is determined.

$$Capacity\ Rating\ (Ah) = \frac{Rated\ Power\ (W)}{Rated\ Voltage\ (V)} \times Operating\ hours\ (h)$$

Equation 1. Battery Pack Capacity Rating

$$\#_{batteries} = \frac{Battery\ Pack\ Capacity\ Rating\ (mAh)}{Rated\ Cell\ Capacity\ (mAh)} \times 3$$

Equation 2. Number of battery cells required

$$\#_{lines} = \frac{\#_{batteries}}{3}$$

Equation 3. Number of parallel-lined battery cells

A monocrystalline solar panel is used in this study. To determine the rated power of the solar panel needed to fully charge the battery pack of the PMS:

$$Rated\ Power\ (W) = 12\ \times \frac{Capacity\ Rating\ (Ah)}{Average\ charging\ time\ (h)}$$

Equation 4. Solar Panel Rated Power

A 3S 50A Battery Management System (BMS) is used in this study as the charge controller. The BMS controls the energy flow over the whole system to ensure safety and no unwanted current flows in the devices to avoid damages. Lastly, a 12VDC-5VDC voltage converter is used for power supplication to the microcontroller and microcomputer.

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 system

Figure 8. Interior of Integrated Traffic Monitoring System

Figure 8 shows the developed prototype of the integrated system. The computer system and the PMS enclosed in a weatherproof box are shown.

Figures 8. Deployed system

Figure 8 shows the installed integrated system into the target area of deployment.

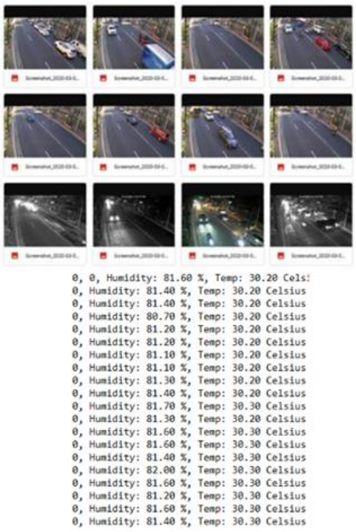

Figure 9. Sample data captured from the imagery sub-system (above) and the telemetric sub-system (below)

B. Calculations done in the development of the system

The following are the determined values of the PMS parameters for its materialization.

$$Capacity\ Rating = \frac{Rated\ Power}{Rated\ Voltage} \times Operating\ hours$$

$$Capacity\ Rating = \frac{40.05\ W}{12\ V} \times 24\ hours$$

$$\boldsymbol{Capacity\ Rating = 80.1\ Ah\ \cong\ 80\ 100\ mAh}$$

$$\#_{batteries} = \frac{Battery\ Pack\ Capacity\ Rating}{Rated\ Cell\ Capacity}$$

$$\#_{batteries} = \frac{80\ 100\ mAh}{2\ 600\ mAh} \times 3$$

$$\boldsymbol{\#_{batteries} = 92.42\ \cong 90\ batteries}$$

$$\#_{lines} = \frac{\#_{batteries}}{3}$$

$$\boldsymbol{\#_{lines} = \frac{90}{3} = 30\ lines}$$

$$Rated\ Power\ = 12\ \times \frac{Capacity\ Rating}{Average\ charging\ time}$$

$$Rated\ Power\ = 12\ \times \frac{80\ 100\ mAh}{10\ hours}$$

$$\boldsymbol{Rated\ Power = 96.12\ W \cong 100\ W}$$

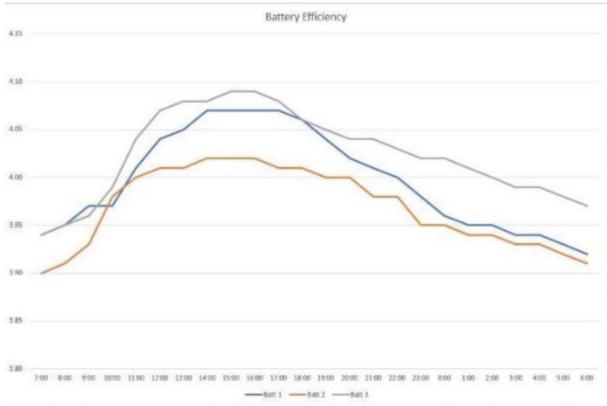

Figure 10. Battery Efficiency graph

The graph shows the average battery levels of the PMS upon charge and discharge operation. In daytime operation, 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 nighttime 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 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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