Internet of Things (IoT) Continuity Challenge: Green Energy Power Consumption

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***Abstract*—The Internet of Things (IoT) has been gaining the attention of various sectors since the promotion in 1990. Billions of physical devices across the globe are connected to the Internet, gathering and sharing all data. The top five challenges have been streamlined as "5C". This study was conducted to address the challenge of "continuity". This research proposed an energy consumption study on the developed solar battery-based IoT water pressure meter. The proposed device has been developed on the basis of the IoT architecture consisting of a perception layer, a network layer and an application layer. Two types of network connectivity have been used: Global System Mobile (GSM) communication and Wi-Fi communication. Two experimental test cases were performed to the study of power consumption. The data collected in the first test case serves as primitive data (indoor) and the second test case serve as comparative data (outdoor). The viability of the battery was examined and presented. The results demonstrated the prolonging of battery life with the improvement on software framework and the increase in the charging rate of solar panels.**

***Index Terms*—Internet of Things (IoT), power consumption, green energy, solar power.**

I. Introduction

Internet of Things (IoT) help improve efficiency and productivity in a wide range of areas [1]. The number of IoT technologies used has risen from 13% in 2014 to around 25% today. The top five challenges have been streamlined as "5C of it", they are Connectivity, Continuity, Compliance, Co-existence and Cybersecurity. In order to be successful in the IoT, the technical challenges of the 5Cs IoT must be conquer. An in-depth understanding of these challenges will provide a strong foundation for implementing and deploying the IoT system. The use of proper design and validation will ensure the delivery of IoT.

Hence, this study was conducted to address one of these challenges, the "Continuity". Securing and prolonging battery life is one of the most important considerations for IoT devices. For industrial IoT devices, a battery life of five or ten years is commonly expected. In the case of medical devices such as pacemakers, the life span of the device can make the difference between life and death. Battery failure is not a viable option. This research proposed the development of a low-level water pressure measurement system. The system is developed based on IoT architecture, which consists of three aspects: perception layer, network layer and application layer [2]. Arduino Uno is used as the microcontroller which connects via GSM or WiFi technology. An application system is developed for collecting and monitoring water pressure and power consumption in the selected urban area. Two test cases were conducted to study the energy consumption pattern of the developed prototype. First, an indoor test case was conducted to visualize the prototype 24-hour power consumption pattern without the solar panel power supply. Second, an outdoor test case in which the prototype was connected to solar energy and exposed to sunlight. A week's worth of data was gathered for the outdoor test case. The results were benchmarked and analyzed.

II. Literature Review

A. Water Pressure Sensor

Water pressure sensors are frequently used to measure the water level in a tank, or the rate of change in that level. The sensor is mounted to the top of an open-ended tube submerged in the container. When the water level increases, the air above the water in the tube is compressed, thereby increasing the pressure on the sensor. An analog-to-digital converter (ADC) is used to convert the sensor signal to a digital value [3]. The sensors can also be used to measure the pressure in pipes where water is flowing at the depth of a submerged object or underwater.

Water pressure sensors generally contain a physical diaphragm, often silicon, which bends when the pressure is applied. The diaphragm is a strain gauge that varies its electric resistance when the force is applied. This resistor will change the sensor output voltage.

Certain water pressure sensors provide zero-based outputs, where zero-pressure gives no output signal. For instance, their output can range from 0 to 5 V. While certain water pressure sensors shows a zero-pressure voltage, with a range like 1-5V. Fig. 1 shows the water pressure sensor specification graph with (1) showing the equation:

$$V_{out} = V_{cc}[0.6667P + 0.1] \quad (1)$$

B. Solar Power Energy

Solar power is one of the most promising renewable sources used globally to meet the growing demand for electricity [4]. Solar power is where electricity is processed through the conversion of sunlight into electricity. Sunlight is collected directly either with photovoltaic or by concentrated solar energy. There are two types of solar cells available

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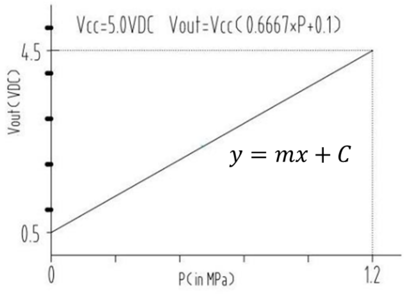

Fig. 1. Water pressure sensor specification (in MPa).

which are monocrystallines and polycrystallines (Fig. 2). Polycrystalline produced energy more easily than monocrystalline, which makes it inexpensive [5]. But for the most part, monocrystalline is more effective than polycrystalline.

Initially photovoltaic used only for small and medium sized applications such as the calculator where the calculator powered by only one solar cell. As for the progression in time, the cost of solar electricity has fallen. There has been an increase in the number of grid-connected solar photovoltaic systems and utility-scale power stations with hundreds of megawatts under construction [4].

The solar power output is depending on the time which that the power output reaches the maximum and minimum power output. Table I show the maximum and minimum power output of polycrystalline with specification 12V, 250mA, 3W. Equation (2) shows the lithium-ion battery charge time using solar [6]:

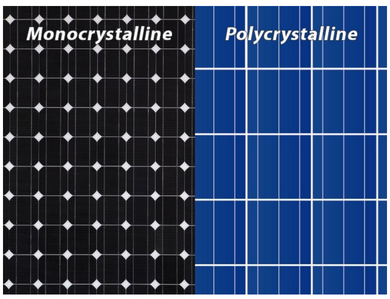

Fig. 2. Monocrystallines and polycrystalline solar panel.

TABLE I
MAXIMUM AND MINIMUM OUTPUT POWER [4]

Condition	Sun's position		
	Sunrise	*Upward*	*Sunset*
Maximum (W)	2.4W at 4pm	1.7W at 12pm	1.63W at 5pm
Minimum (W)	1.21W at 9am	0.38W at 12pm	0.4W at 5pm

$$T = (B/P) * 2 \tag{2}$$

Where:
T = Total time for charge (hours)
B = Battery capacity (watt hours)
P = Panel Power (watts)

The environmental factors will likely influence charging time, such as heat and angle [6]. Power output of a panel will decrease around 0.5% per degree over 25°C. While the panel rotates away from the sun, power output drops (Table II). Besides, any haze or clouds will slow down charge time significantly.

TABLE II
ANGLE TO SUN AND POWER DROPS [6]

Angle to Sun	% Output
90	100%
75	97%
60	88%
45	77%
30	61%
15	32%
0	3%

C. Power Consumption

The power consumption is defined when the current of the electrical circuits circulating on the components of the appliance is activated and is measured in watt (W). Equation (3) shows the power consumption formula in which the measured voltage (V) is multiplied by the current (A) [8]. For the power consumption of the device powered by the batteries, the most relevant use of the current limited power supply is the lithium-ion battery. This is popular in the use of the small sensor device where the batteries are capable of powering the device without any problems.

$$P = IV \tag{3}$$

Where:
P = Power (watt, W)
I = Current (ampere, A)
V = Voltage (volt, V)

III. METHODOLOGY

The proposed system is developed based on the IoT architecture, which comprises three components: a perception layer, a network layer and an application layer. Two types of prototypes using different communication technology are developed, GSM and Wi-Fi. The details of the system development and data acquisition are presented and discussed.

A. System Architecture

The proposed system's perception layer focuses primarily on the part of the device's hardware that includes design, components, circuit design and algorithms. IoT platform, Adafruit is used in the application layer for data visualisation after the data acquisition process. The network layer acts as the connector between the perception layer and the application layer using GSM and NodeMCU communication technology along with their respective network protocol. The developed system concentrates on the condition of the water level where the water pressure is measured using the developed device.

B. Prototype

Fig. 3 illustrates the prototype design with Arduino Uno. The Arduino Uno board was selected as the board is programmable and the price of the board is inexpensive. Arduino IDE provides easy programming via Type-B USB connector. The water pressure sensor G1/4 1.2MPa plays a role in measuring the water pressure. The sensor will measure the pressure value once the water flows through the attached pipe. GSM and NodeMCU served as communication technology.

The collected data will then be transmitted and visualized on the IoT platform.

There is also an easy on-site view of the data via the liquid crystal display (LCD). A 16x2 Inter-Integrated Circuit (I2C) LCD was chosen on account of its compatibility with the Arduino board. The LCD component acts as the display for the reading gathered from the sensor. A stackable solar charger shield is used as an energy harvester for in-field charging in cooperation with solar panel and lithium-ion battery. The maximum current provided by the board can be up to 600mA. The prototype operates with 3.7V and 4.8AH lithium-ion batteries. The battery had a parallel connection. Parallel connectivity increases battery capacity from 4.8AH to 19.2AH.

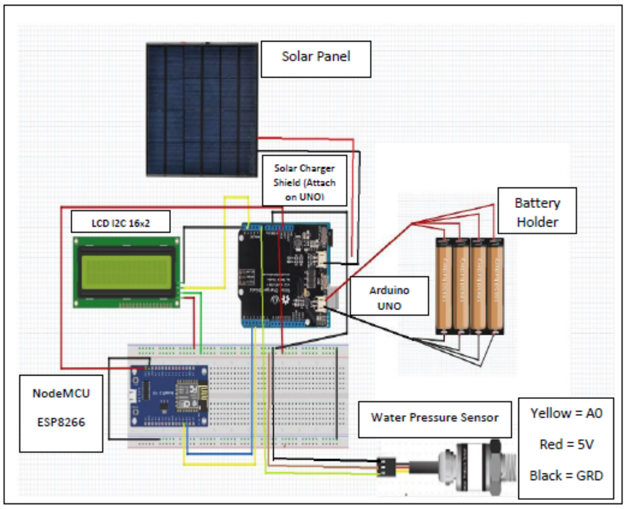

Fig. 3. Prototype circuit design.

C. Test Case Design

Two test cases were conducted to study the energy consumption pattern of the developed IoT device. The data collected in the first test case serves as primitive data and the second test case serves as comparative data. In the first test case, the prototype was operated indoors. Electric variables, voltage (V), current (A), power (W) were collected and computed. In the second test case, the prototype was operated outdoors. The same electricity variables were collected. The multimeter was also used for manual measurement of the data. The result is used for data validation during the theoretical and practical comparison of the power consumption pattern.

IV. Result

The study is still in the preliminary stage and yet this pilot test was conducted on data collection and analysis and therefore significant preliminary results were obtained.

A. Result Validation

The section is intended to validate the electrical variables obtained from the prototype. Fig. 4 shows the voltage measurement obtained using the prototype and multimeter. The graph visualized the data measured from the prototype and multimeter were nearly the same with an error range close to 0.05V. The results show the reliability of the data derived from the prototype. The graph shows the highest voltage at 3.83V while the battery pack is fully charged and the lowest at 2.76V while the voltage decreases. The device stops transmitting data when the voltage falls below 2.8V and stops operating when the voltage falls below 2.3V. The voltage increment at 12.00pm and 6.30pm indicates the change of new battery pack after the voltage falls below 2.8V.

B. Electrical Variables

Fig. 5 shows the relation of prototype's electrical variable. These electrical variables: voltage, current and power are correlated [8]. Variable increments and decreases are relative. The tendency of each variable gradually decreases over time. The device stops data transmission after the voltage less than 2.8V. The prototype stops working after attaining low voltage at 2.3V and 8.11A. The device takes about 6-9 hours of operation on the battery without utilizing solar power. The battery pack was changed twice throughout the experiment: 12:00pm and 6.30pm.

C. Voltage Variation (Case 1- Indoor)

The test case aims to investigate the power consumption pattern for the device throughout the hours without the use of solar panel. Theoretically, Prototype 1 (using GSM) approximately consumed a total of 5.95 watt-hours can last for 12 hours with the battery capacity of 71.04 watts. While Prototype 2 (using NodeMCU) estimably consumed a total of 1.51 watt-hours can last for 47 hours with the same battery capacity.

Fig. 6 shows the operating hours of Prototype and Prototype 2. The graph shows that Prototype 1 can operate for up to 24 hours without the use of a solar panel, whereas Prototype 2 can only operate for up to 6 hours. Comparing to the theoretical estimation result, the data shows that the operating hours of Prototype 1 were longer than expected, whereas Prototype 2 was shorter than expected (Table III).

D. Voltage Variation (Case 2 - Outdoor)

The test case aims to investigate the power consumption pattern for the device throughout the hours with the use of solar panel. Polycrystalline solar panel with the specification 12V, 0.25A, 3W was used. The panel can produce up to 24 watts a day with 8 hours of full-charge under the sun. Theoretically, with the use of solar panel, Prototype 1 (using GSM) approximately consumed a total of 5.95 watt-hours can last for 16 hours with a battery capacity of 71.04 watts. While Prototype 2 (using NodeMCU) estimably consumed a total of 1.51 watt-hours can last for 63 hours with the same battery capacity.

Fig. 7 shows the operating hours of Prototypes 1 and Prototype 2. The graph shows that Prototype 1 operated up to 38 hours with the use of solar panel, whereas Prototype 2 can only operated up to 12-17 hours. The operating hours of Prototype 1 were longer than expected, whereas Prototype 2 was shorter than expected (Table III).

The inconsistent operating hours for Prototype 2 were caused by the solar charging rate. Table IV shows the average charging rate for Prototype 1 and Prototype 2. This charging rate table were formed based on the weather condition (Sunny) throughout the hours. Once the charging rate fell below 60%, operating hours decreased from 17 hours to 12 hours.

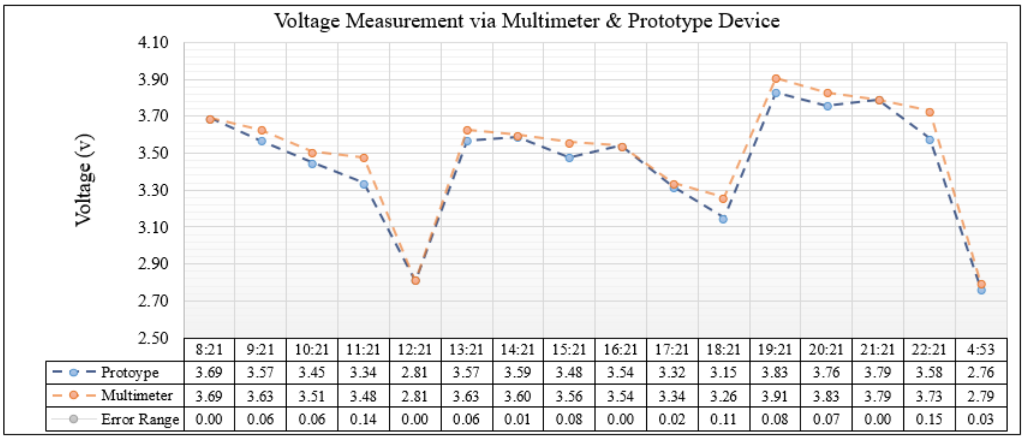

Fig. 4. Voltage measured using multimeter and prototype.

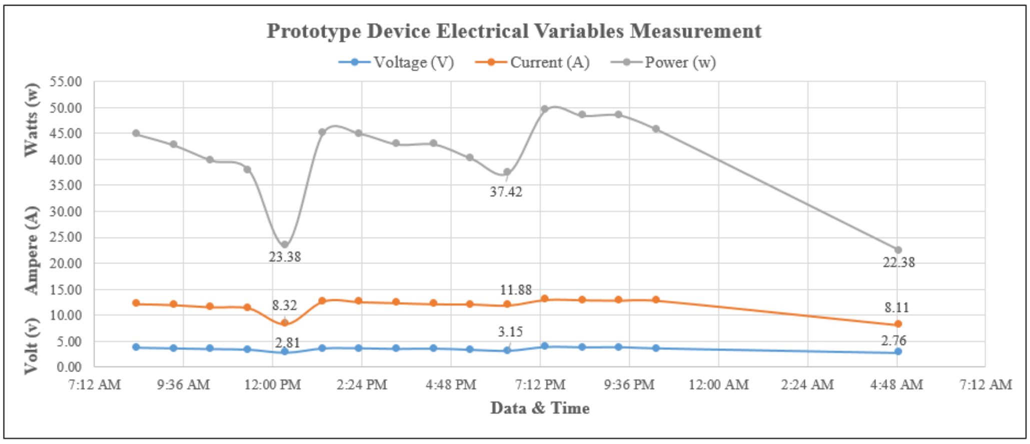

Fig. 5. Prototype electrical variables.

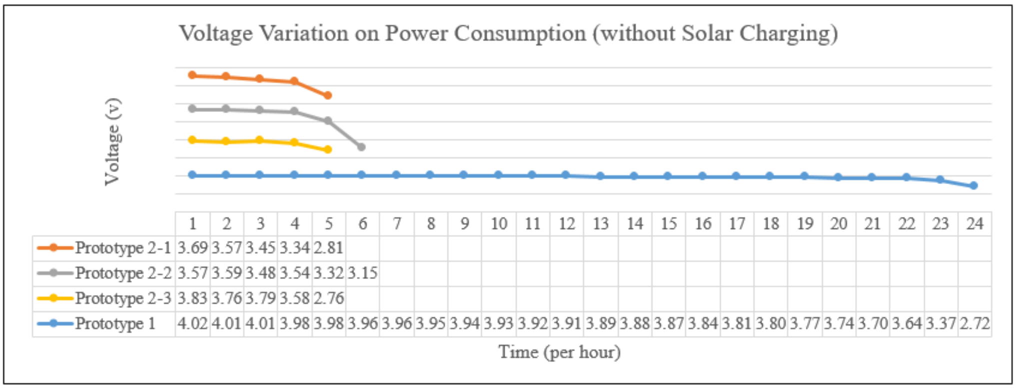

Fig. 6. Prototype 1 and prototype 2 operating hours (indoor).

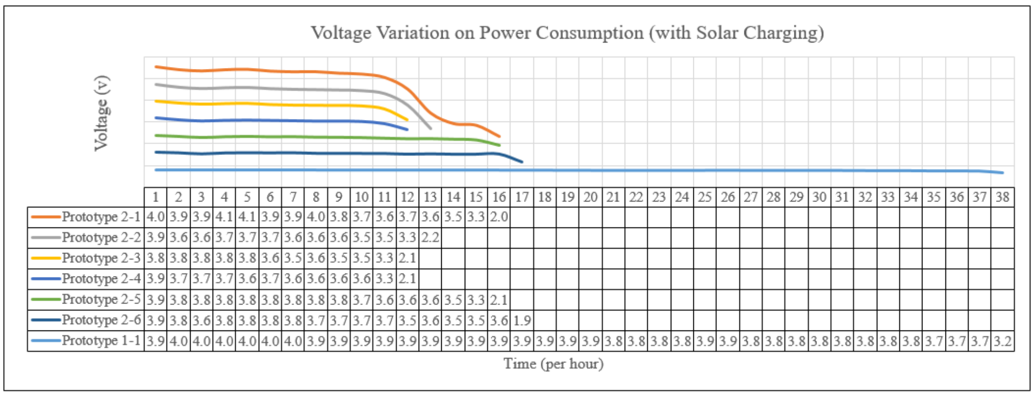

Fig. 7. Prototype 1 and prototype 2 operating hours (outdoor).

TABLE III
THEORITICAL AND EXPERIMENTAL OPERATING HOURS FOR PROTOTYPE 1 AND PROTOTYPE 2

	Prototype 1		Prototype 2	
	Theory	Experiment	Theory	Experiment
Case 1 (Indoor)	12	24	47	6
Case 2 (Outdoor)	16	38	63	17

TABLE IV
WEATHER AND CHARGING RATE

Weather	**Sunny**	**Fine**	**Cloudy**	**Charging Rate (%)**
Prototype 2-1	10	6	0	62.50
Prototype 2-2	7	3	3	53.85
Prototype 2-3	6	5	1	50.00
Prototype 2-4	1	3	7	9.09
Prototype 2-5	10	6	0	62.50
Prototype 2-6	11	6	0	64.71
Prototype 1-1	24	14	0	63.16

V. DISCUSSION

The two prototypes are developed based on the same architecture, but with different communication technology. The study expected higher power consumption in Prototype 1 compared to Prototype 2 in both test cases. In fact, Prototype 1 shows its sustainability throughout the process while the opposite for Prototype 2. This can be explained by the software framework of two prototypes. ”JeeLib.h” was applied on the first prototype and the prototype has been set to standby mode with one-hour intervals. The result showed the software framework play roles in energy conservation on the IoT device. The charging rate has also influenced the performance of the solar-powered IoT device. The results show a low charging rate on both prototypes. The situation was caused by the environmental factors: the angle to the sun, haze, cloud and heat [6].

VI. CONCLUSION

This study aims to improve the prolonging of the battery life of an IoT device. The results demonstrated the improvement at the perception layer: software framework and solar panel charging rate. Based on the result, the achievement is partial and there still space of improvement. The study will be continue by increasing the power generates by the solar panel and the replacement of the lithium-ion battery.

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