Towards the Implementation of Energy Harvesting for IoT Sensor Nodes in an Early Warning Flood Detection System

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***Abstract*—**Flood sensors are deployed to measure the water level of rivers in areas prone to flooding. Flood is a frequent event in many places and the after effect almost always results in loss of properties and lives. Deploying sensors in remote areas to provide significant benefit in mitigating the after-effects of flood, however, it is not simple as the nodes would require a constant source of clean energy. This research explores the potentials of energy harvesting as a means for the sensor nodes to be self-sustaining by using a clean source of energy in order to achieve constant monitoring of water levels in remote flood-prone areas.

***Index Terms*—**Energy harvesting, IoT sensor node, flood sensor

I. Introduction

Flooding is a natural disaster that happens frequently in Malaysia. The first common type of flood is the monsoon floods, which happens annually due to the monsoon season, commonly affecting the east coastal cities of Peninsular Malaysia. The worst monsoon flood that had happened in the past few decades locally was the 2014 monsoon flood, which had affected more than 200,000 people and had claimed 21 lives. The other type which is the flash flood, can happen anywhere and anytime due to Malaysia's tropical rainforest climate whereby it rains throughout the year, commonly affecting areas around rivers such as along the Klang river in Kuala Lumpur and Kuantan River in Pahang, as well as areas which do not have good and effective water channeling and drainage systems.

The Stormwater Management and Road Tunnel (SMART) in Kuala Lumpur was constructed to rectify the second issue in which when there is a sudden and sustained heavy rain and when the water level starts to rise, the tunnel can be used to drain out the water excess to reservoirs or other water channels. SMART tunnel under normal operations is otherwise used as an expressway for light vehicles to enter the heart of the city. Other places, however, do not have this kind of mitigation and thus, quick responses and swift actions are needed to minimize damage as well as evacuation of people when need be. Therefore, a constant monitoring over the water level for rivers and drains that are commonly causing flood to the nearby areas is needed.

In the current standard operating procedures workers are sent or stationed at key areas of the rivers, such as the upstream part of the river, or the intersection of a few rivers, to do the monitoring. This method is unreliable as a worker might not be there all the time to monitor, and there could also be human error during the measurement process. As such, an IoT sensor node could take over the process of monitoring, in which constant sampling of data can be done reliably as well as autonomously.

II. Preliminaries

A. Wireless Sensor Network

Wireless Sensor Network (WSN) is a wirelessly interconnected network of nodes that has one or more sensors attached to each node that can provide meaningful data for various purposes be it monitoring of the environment, early detection of disasters, surveillance or other tasks. Originally, WSN was originally developed as a means for military surveillance but has currently been adopted into the industry as well as consumer appliances.

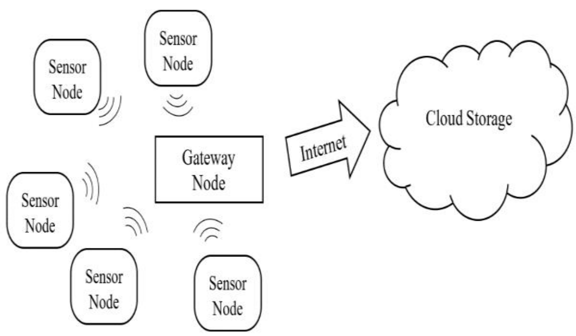

Fig. 1. Typical wireless sensor network structure

The most basic model of a WSN involves one sensor node and a gateway. Sensor nodes includes sensors to gather data, microcontrollers to operate and automate the process, batteries to power up the device and transmitter

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modules, usually radio frequency modules to send data to the gateway. The latter will gather data from the sensor node to process it and alert users if a certain threshold is reached. Recent gateways are also equipped to be Internet-of-Things (IoT), the capability to connect to the internet and have the data be stored in a cloud-based database where the date can be collated and analyzed. Fig. 1 and Fig. 2 below shows the model of WSN and a basic Sensor Node configuration.

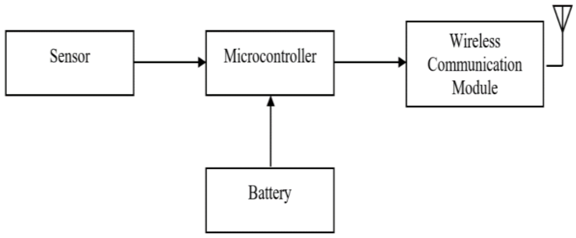

Fig. 2. Typical wireless sensor node structure

Since the process of data sampling by a sensor node can be preprogrammed to be done autonomously, this device provides a significant advantage for the purpose of monitoring. The idea of environmental monitoring with WSN is not new [1]-[7], in [8] the authors suggested a general monitoring system for disaster management in Malaysia which consists of flood monitoring by measuring water level, installing tiltmeters at hillsides for monitoring landslides as well as haze by measuring the Air Pollutant Index (API). With the correct sensor according to the specific objectives, a sensor node can be re-purposed to monitor different purposes. Also stated in the paper are applied cases of WSN in disaster management including, flood detection in Honduras, flood and landslide monitoring in Indonesia, air pollution monitoring in Mauritius and volcanic eruption monitoring in Ecuador. In our research work we have focused on the use of WSN for flood detection.

B. *WSN-based Flood Sensor*

There are a number of configurations in hardware and software that had been done previously according to the focus of the projects as well as selections due to limitations that was present. One research described in [9] proposed the use of contact water sensor, Peripheral Interface Controller (PIC) microcontroller, and Global System for Mobile communications (GSM) module to alert users by Short Message Service (SMS) to their phones for spontaneous alerts in the event of flooding.

Another research described in [10] have similar hardware, with Zigbee as the means of communication but with different sets of sensors. The former has a simpler contact water sensor system while the latter combined multiple sensors: rainfall gauge, temperature, water level as well as humidity; to determine the severity of the status. This way, the system can provide a better resolution status of the flooding, rather than just an either a “yes or no” status.

Further advancement of technology over the years brought about newer and more reliable as well as cheaper hardware. Such progress introduced the ultrasonic sensor as a better selection as it can accurately determine the water level. Another hardware that was made popular for the availability and price was the ATmega microcontroller by Atmel. This can be seen in projects proposed by [11], and [12].

A real-world implementation was done in [13] where they proposed and tested a wider-casted network where many buoy-type sensor nodes connected to multiple gateways were deployed and users will get notifications via SMS. This project was tried and tested at the Hungarian-Slovakia border. Another implementation was done by [14] in Nampung, Thailand, suggesting the use of rain gauge and a local display at the monitoring center for flood status.

In [15] a community-driven WSN was proposed where the residents of the area can buy and own their sensor nodes to increase the resolution of data and have the data available for public access. This push for crowdsource data acquisition as well as open data movement was inspired by the Oxford Flood Network. Another concept used in this project is the gateway was equipped with IoT capability where the data acquired by the sensor is passed to the gateway which then pushes them to be stored in an online database.

A unique setup over previously mentioned configurations done by [16] was done by making the sensor node itself IoT-capable which bypassed the usage of gateways altogether. This can further speed up the process of data sampling and storing to the database as every node is connected directly to the internet without intermediaries. However, this setup is quite costly as each of the nodes requires a Raspberry Pi and a 3G/4G modem with cellular network service.

III. Energy Harvesting

One crucial feature for WSN is that the sensor nodes should always be operational to have constant monitoring and avoid loss of data sampling. Normally, sensor nodes would be equipped with batteries but over time, the energy of these batteries will become depleted, and either a recharge or a change is needed. Recharging by normal means is not feasible as sensor nodes are normally deployed in remote areas where there are no connections to the power grid. To alleviate this issue, energy harvesting is a very effective means to be introduced into the system in order for the nodes to be self-sustaining and can remain continuously operational. The model of a sensor node, taken from Fig. 2 is modified as shown below in Fig. 3.

Do note that the difference of configurations between Fig. 3 and 4, where the battery is either absent or present. This research will be focused more on the latter configuration. There are a number of energy harvesting methods available currently and there are studies which have been done to evaluate whether the methods are suitable to be used for WSN. One such research was done, a study specifically for WSN over water distribution system in [17]. Techniques stated was energy harvested from vibrations by three different mechanisms: piezoelectric, electromagnetic and electrostatic. Since the system is deployed for water monitoring, energy can also be harvested from the flow of water itself by either mechanically harvesting using hydraulic turbines, or non-mechanically by using piezoelectric cantilever or piezoelectric polymer that vibrates from the flow of water.

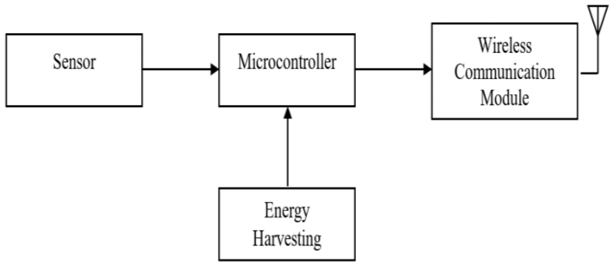

Fig. 3. Sensor node model with energy harvesting powering the system directly.

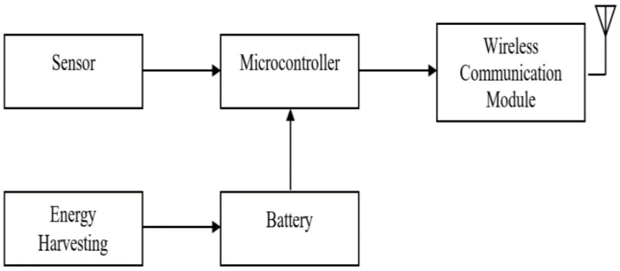

Fig. 4. Sensor node model with energy harvesting

A similar and more extensive study [18] was also done whereby different sources of energy suitable for harvesting were evaluated for WSN, classified by either ambient sources or external sources. For ambient sources, Radio Frequency (RF), solar, thermal, and flow (wind and water) were listed. Categorized under external sources are: mechanical-based which are from vibration, pressure and strain-stress; and human-based which are by actions and physiological. Described in the following section are the renewable energy sources which were taken into consideration for this project.

A. Photovoltaic Cells

Commonly known as solar panels, these cells are relatively easy to obtain and set up. Solar panels are a popular choice for harvesting energy from the environment and more solar farms are being built all around the world in the long term pursuit of achieving sustainable energy. Since the panels are running on DC power, they can be fed in directly into the system.

The output of this method can vary from µW to MW range depending on the size of the panels as well as the intensity of light it receives. However, the main limitation of this method is that it needs to be exposed to the sunlight to work which limits it to harvest only during daytime. Thus, batteries are needed to store up the power for the night. Batteries are also needed for the system to operate in less-than-ideal conditions such as cloudy or rainy days. In addition the weather conditions in some countries are not feasible for year long operation of the solar panel.

B. Hydropower

This method converts the flow of water into electrical energy using rotating turbines. As the sensors will be deployed over rivers, this can be a good method as rivers will always have flowing water, providing a continuous source of clean energy as opposed to a time-limited energy sources such as solar energy.

A typical pico-hydro generator can produce up to 5kW of power, but it depends on the flow of water going into the device. The challenge, however, will be anchoring and maintaining a tethered connection between the generator and the sensor node. Another challenge is that the generator inlet could get clogged up thus a filter is needed to be installed at the inlet to prevent this.

C. Piezoelectric

A piezoelectric device generates electricity from vibrations. A focused study for energy harvesting with piezoelectric for WSN was done in [19] in which a test was done to sample temperature and vibration data. Thorough calculations were done with the energy requirements of the system stated in the research, and with proper low-power configuration for the system, mainly for the microcontroller and communication module, the research claimed to have managed to prolong the battery from operating for 7000 hours to 10000 hours.

D. RF and Wi-Fi harvesting

Another focused study was done in [20] which shows the feasibility of harvesting energy from ambient Wi-Fi and cellular signals. Specially built rectennas with different configuration of circuits were constructed for both signals and were exposed to the ambient radio signals and real results of power harvested from the different frequencies were shown in comparison to calculated results.

E. Thermal Electric Generator (TEG)

A TEG harvester has two different sides and works based on the temperature gradient between the two sides. Electricity is then produced whereby the higher the difference, the higher the electricity it generates. It follows equation (1) below where V is the voltage produced, ΔS is the Seebeck coefficient and ΔT is the temperature gradient:

$$V = \Delta S \text{ x } \Delta T \tag{1}$$

A DC-DC converter can be put in between the device and the system to bring up the voltage produced. The TEG device then can be positioned on the water surface as the sunlight can heat up the upper surface while the flow of water can dissipate the heat from the lower surface.

All the above-mentioned energy sources are valid for powering up a sensor node in a WSN, but further research is required to best suit the hardware requirements set in this research. Another notable idea to be included in this research is whether a multi-source energy harvesting would be better than a single source. A study in [21] demonstrated that ~~a~~ multi-source would be beneficial, where the thermo electric generator which served as the alternate source in combination with solar power will be activated to power up the system when there was an extended absence of light due to varying weather conditions.

The next consideration after selection of sources of energy would be energy management to regulate and manage the harvested energy and avoiding power loss. This solution must strike a balance between the energy harvested and energy being used. In [22] it was stated that the process of harvesting from these energy sources is a discontinuous process and the consumption ratio can vary such that it is more or less than the generated power. As such, the operational mode of the node itself can be configured to be continuous or discontinuous. Both cases of generated power being more than consumed power, and consumed power being more than the generated power as demonstrated in Figures 5(a) and 5(b) [22].

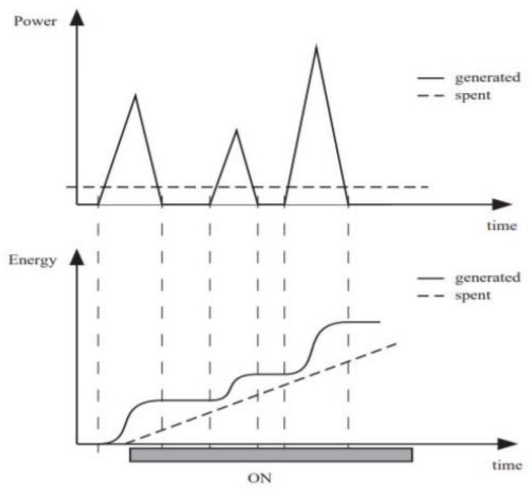

Fig. 5 (a): Power generation and consumption in continuous operation [22]

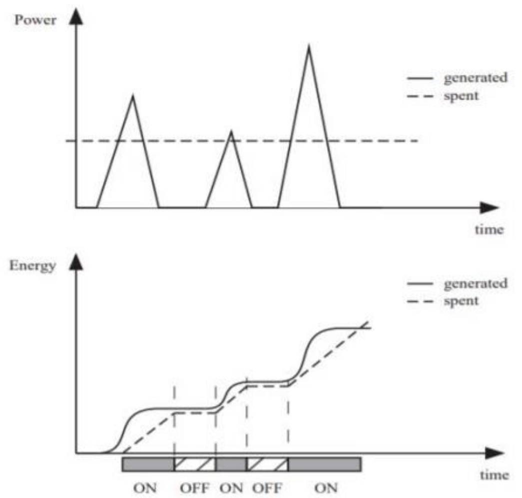

Fig. 5. (b): Power generation and consumption in discontinuous operation [22]

In [22] a few Power Management Integrated Circuits (PMIC) were recommended. These PMIC are specialized Integrated Circuits that can reduce power consumption as well as increase the longevity of batteries in IoT devices. The recommended PMIC are the AEM 10940 by e-peas, S6AE10xA by Cypress, Bq251120 by Texas Instruments, MAX14720 by Maxim Integrated and SPV1050 by STMicroelectronis. Each of these PMIC has their own specific features which fits in different usages and scenarios.

The next important step in our design process is the selection of batteries to store the energy harvested and power up the sensor nodes. Ideally, the size of the battery should be small to fit in with the sensor node, but capable to store enough capacity to power up the node, preferably in continuous mode. Table I below lists common battery technologies with each of their own pros and cons [22].

TABLE I: BATTERY TECHNOLOGIES WITH PROS AND CONS

Technology	Pros	Cons
Rechargeable batteries	• Rechargeable	• Limited charged-discharge cycles Feasible with energy harvesting
Non-rechargeable batteries	• Convenience • Cost	• Replacement Ecology
Super capacitors	• 'Unlimited' charge-discharge cycles	• Self-discharge
Printable batteries	• Easy fabrication process Customizable cell (voltage, capacity, size) • Thin and flexible	• May damage at 40-50 ℃ • Not mature enough
Solid-state batteries	• Easy integration with IC • Easy to miniaturize • Thin and flexible	• Low power density • Not mature enough

IV. PROBLEM DESCRIPTION

Deployment of flood sensors is needed in areas that are flood prone as a measure of early detection for quick responses and damage mitigation. IoT sensor nodes will give a significant advantage over the traditional method of having a person to monitor over a period of time as IoT sensor nodes can do it autonomously and accurately in predefined sampling intervals. However, deployment of these nodes in remote areas can be difficult as constant power are needed while no connections to the electricity grid are available. Furthermore, low-power configurations for the microcontroller and the communication module are needed for a battery-powered node to sustain for a longer duration. An energy harvesting method is therefore needed to recharge the battery to keep it from depleting. Additionally, more sensors deployed over the area will add up to the accuracy of data. However, deploying more sensors will translate into more cost being incurred. Therefore, self-sustained, low-power, low-cost IoT sensor nodes are required for deployment of flood early warning monitoring system in remote areas.

V. Proposed Methodology

A. Overall Hardware Setup Description

The setup of hardware for this research is a further development of our previous setup done in [15] over Kemaman river in Terengganu, whereby an ultrasonic sensor is used to measure the water level of the river. The sensor is connected to a similar Arduino microcontroller unit as shown in Fig. 6. However, as means of communication, a LoRa transmitter is used as opposed to GSM module done in [13] as the latter module consumes a lot of energy subsequently draining the battery in a very short time. Another addition to the previous setup in [15] will be a selected energy harvesting system to complete the IoT sensor node following the setup in Fig. 7.

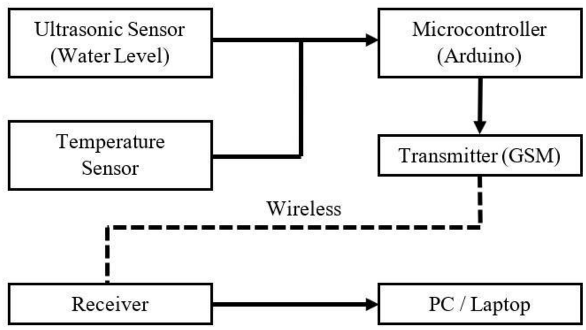

Fig. 6. Hardware setup of the flood sensor prototype done in [13].

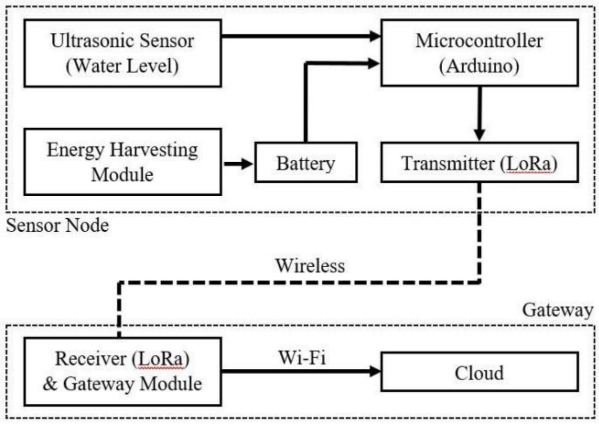

Fig. 7. Proposed hardware setup of the flood sensor prototype.

Since the node will be exposed to varying weather conditions, a waterproof container is needed to protect it. As for the placement, the node will then be mounted at a point of interest over the river, typically where two smaller rivers joined into a bigger one, as well as certain key points of the river (e.g. before reaching residential areas or nearby flood-prone areas). Fig. 8 shows the mounting of the node on a bridge over the river for the setup in [15] with Fig. 8 (a) showing the solar panel being used and mounted with the sensor node, Fig. 8 (b) showing how the node mounted at the side of a bridge directly above a river and Fig. 8 (c) showing the weatherproof container used as the casing to protect the electronics from the rain.

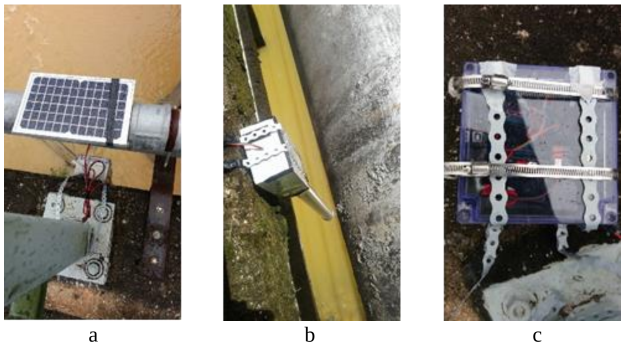

Fig. 8. Mounting of sensor node in [15] over river in Kemaman, Malaysia

A gateway that is connected to the internet is used as a means of receiving the data collected and sent by the sensor and upload the data to an online database. Since the gateway needs to always be ready to receive and upload the data, it needs to be placed where power can constantly be supplied, typically in offices or selected homes. The planned gateway model to be used is from the Dragino LoRa IoT Development Kit shown in Fig. 9. Note that this kit includes the LoRa receiver built in the gateway as well as the Arduino LoRa shield for the transmitter.

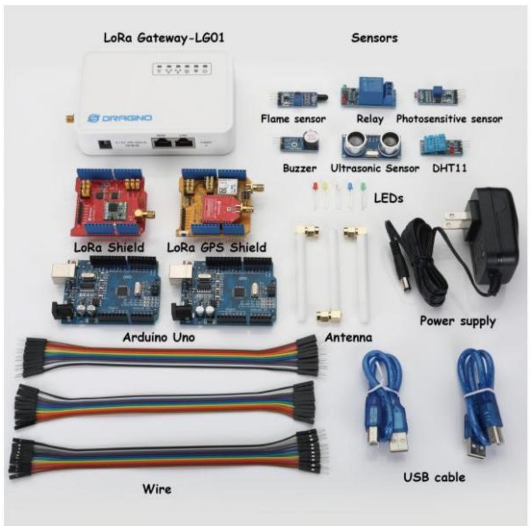

Fig. 9. Dragino LoRa IoT development Kit

The LoRa Gateway LG01 has a number of hardware features built in to support the functions needed for IoT such as the built in LoRa receiver as well as Wi-Fi to minimize the number of components needed to be deployed. The gateway also has support for MQTT protocol in which IoT devices are using to send data.

B. Supercapacitor Based Energy Storage Circuit

Regardless of the source of clean renewable energy, it is essential to have a circuit to store the energy that has been generated from the energy harvesting source. In this section we describe the construction of a supercapacitor-based circuit for storing energy collected from any energy harvesting source.

1) Supercapacitor charging

When an increasing DC voltage is applied to a discharged Capacitor, the capacitor draws a charging current and "charges up". If a resistor is connected in series with the capacitor forming an RC circuit, the capacitor will charge up gradually through the resistor until the voltage across the capacitor reaches that of the supply voltage. Capacitors are able to store electrical energy they act like small batteries and can store or release the energy as required.

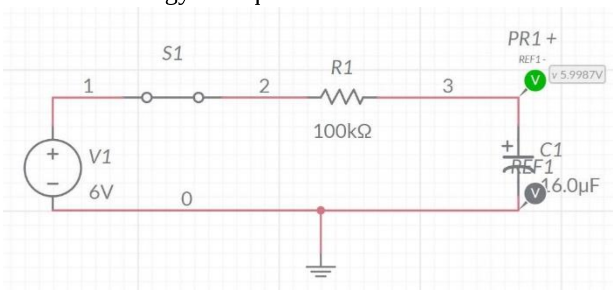

Fig. 10. Multisim circuit schematic representing supercapacitor charging

The charge on the plates of the capacitor is given as:

$$Q = C\,V_C \tag{2}$$

This charging (storage) and discharging (release) of a capacitors energy is never instant but takes a certain amount of time to occur with the time taken for the capacitor to charge or discharge to within a certain percentage of its maximum supply value being known as its time constant, τ. The time constant is also called the transient response time, and required for the capacitor to fully charge.

This transient response time τ, is measured in seconds. The formula to calculate the transient response is:

$$\tau = RC \tag{3}$$

From Equation (2), the voltage across the value of the voltage across the capacitor V_C at any instant in time during the charging period is given as:

$$V_C = Q/C \tag{4}$$

$$V_C = V_S\,(1-e^{-t/\tau}) \tag{5}$$

The charging curve for a RC charging circuit is exponential, the capacitor never becomes 100% fully charged due to the energy stored in the capacitor

When we open the switch and place a load in series with the capacitor, the capacitor will discharge. As the capacitor discharges, it loses its charge at a declining rate. As the voltage across the plates is at its highest value, maximum discharge current flows around the circuit. With the switch is opened, the capacitor starts to discharge, with the decay in the RC discharging curve steeper at the beginning because the discharging rate is fastest at the start and then tapers off as the capacitor loses charge at a slower rate. As the discharge continues, V_c goes down and there is less discharge current. So, an RC circuit's time constant is a measure of how quickly it either charges or discharges.

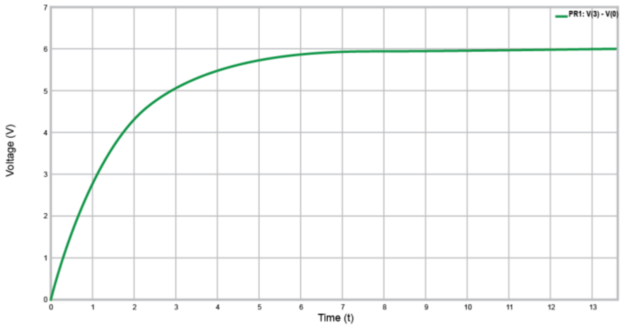

Fig. 11. Supercapacitor charging graph

2) Supercapacitor discharging

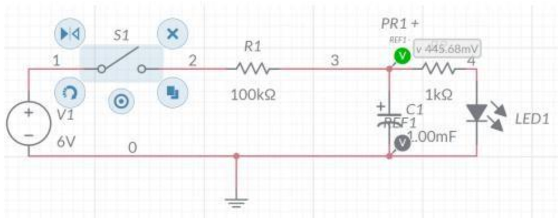

Fig. 12. Multisim circuit schematic representing supercapacitor discharging.

For a discharging circuit, the voltage across the capacitor as a function of time during the discharge period is defined as:

$$V_C = V_S\,e^{-t/\tau} \tag{6}$$

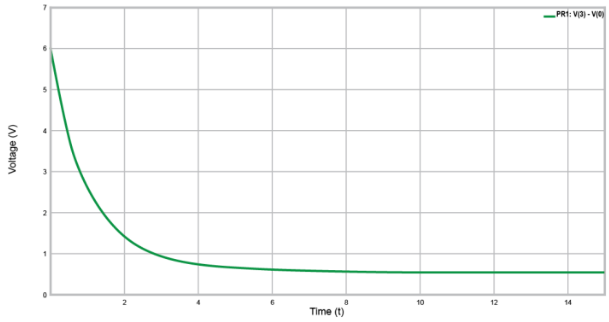

Fig. 13. Supercapacitor disharging graph

3) Supercapacitors in series

Most systems require more working voltage than a single supercapacitor can supply. In systems that demand high voltages, supercapacitors are commonly connected in series. Supercapacitors that are connected in series however do require a balancing circuit as described in the following section.

$$C_T=C_1+C_2+C_3+\ldots C_n \tag{7}$$

4) Supercapacitor balancing

Since there is a tolerance difference between manufactured cells in capacitance, resistance and leakage current, there will be an imbalance in the cell voltages of a series stack. It is important to ensure that the individual voltages of any single cell do not exceed its maximum recommended working voltage (or also known as bank – amount of voltage a capacitor can store) as this could result in overcharging and ultimately reduction in the lifespan of the supercapacitor. Proper cell balancing can eliminate this imbalance.

There are two types of balancing circuit, which are known as Passive Balancing and Active Balancing. However, in this study, we will focus to Passive Balancing as shown in Fig. 14.

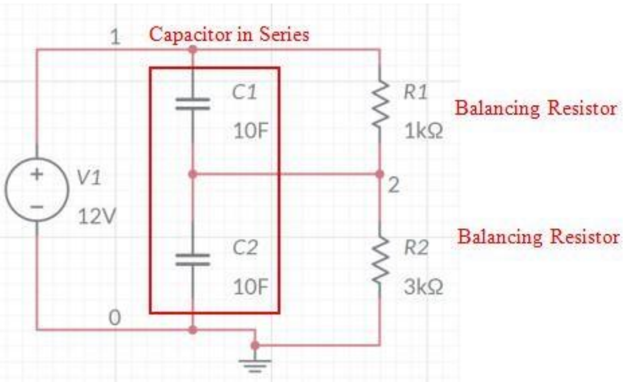

Fig. 14. Supercapacitor in series which incorporates passive balancing.

By having different values of resistors in parallel with the supercapacitors, the supercapacitors with higher voltages will discharge through the parallel resistor at a higher rate than the supercapacitors with lower voltages. This will help to distribute the total stack voltage evenly across the entire series of capacitors. Higher ratio can be used to balance the supercapacitors faster which means a lower resistance value with respect to higher capacitance will result in the higher speed of voltage balancing.

5) Overall energy storage circuit design

For a low-powered energy harvesting circuit, we have designed the circuit as shown in Fig. 15. Since the load needs a 5V input from the harvester, a series-capacitor bank is constructed to increase the voltage bank. Hence, in order to compensate the voltage imbalance in the circuit, the resistors are added in parallel with the supercapacitor. This acts as the voltage divider to help even out the voltage of both capacitors. Fig. 16 shows the charging rate of the supercapacitors for the circuit shown in Fig. 15.

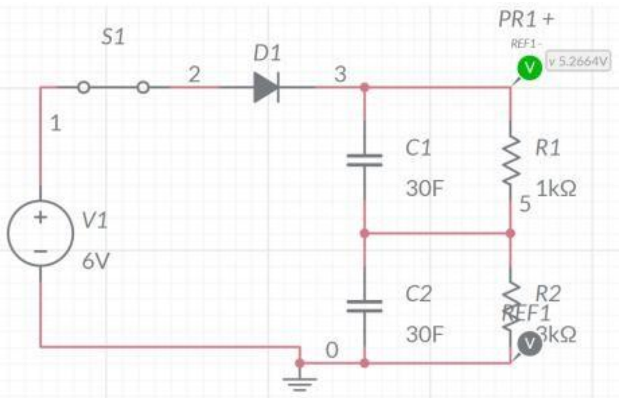

Fig. 15. Multisim circuit schematic representing complete circuit design.

In a real experimental setup, the DC power source in the circuit will be replaced by the photovoltaic cell. Since the total capacitor nominal voltage bank is 6V, we consider the 10% to 20% tolerance of voltage collected from the total voltage of the supercapacitors to avoid overcharging. Therefore, before the supercapacitors are fully charged, the photovoltaic cells or the energy harvester circuit will be disconnected from the storing device as the bank reaches 10% to 20% of the total amount it can accommodate.

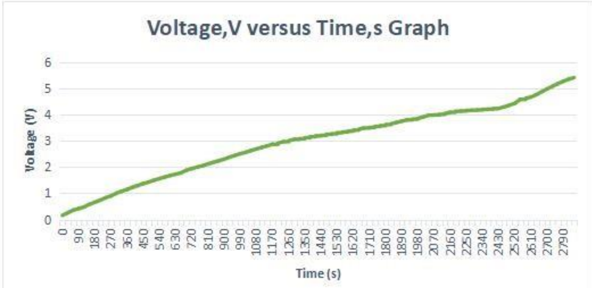

Fig. 16. Charging rate of supercapacitor bank.

VI. Conclusion

Although WSN based environmental sensors is not a new idea, with a suitable energy harvesting system added to the sensor node as well as incorporating IoT, the node can be self-sustained without concerns about running out of power and the data collection can be done continuously without interruptions. These data which is then logged into the IoT database, can then be further used for analysis.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Mohd Aizat Mohd Yazid has conducted the literature review, conducted experiments and written the article. Ahmad Jazlan supervised the project and helped with writing the article. Mohd Zuhaili Mohd Rodzi was the field supervisor. Muhammad Afif Husman provided advice on hardware and software. Abdul Rahman Afif designed and developed sensor nodes and programming for communication with gateway. Hasan Firdaus Mohd Zaki and Deepak Kumar helped to check the contents of the article. All authors had approved the final version.

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References

[1] K. S. C. Kuang, S. T. Quek, and M. Maalej, “Remote flood monitoring system based on plastic optical fibres

and wireless motes," *Sensors and Actuators A: Physical*, vol. 147, no. 2, pp. 449-455, 2008.

[2] B. K. Mishra, D. Thakker, S. Mazumdar, S. Simpson, and D. Neagu, "Using deep learning for iot-enabled camera: A use case of flood monitoring," in *Proc. 10th International Conference on Dependable Systems, Services and Technologies (DESSERT)*, Leeds, United Kingdom, 2019, pp. 235-240.

[3] S. K. Sood, R. Sandhu, K. Singla, and V. Chang, "IoT, big data and HPC based smart flood management framework," *Sustainable Computing: Informatics and Systems*, vol. 20, pp. 102-117, 2018.

[4] T. Perumal, M. N. Sulaiman, and C. Y. Leong, "Internet of Things (IoT) enabled water monitoring system," in *Proc. IEEE 4th Global Conference on Consumer Electronics (GCCE)*, Osaka, 2015, pp. 86-87.

[5] K. Chetpattananondh, T. Tapoanoi, P. Phukpattaranont, and N. Jindapetch, "A self-calibration water level measurement using an interdigital capacitive sensor," *Sensors and Actuators A: Physical*, vol. 209, pp. 175-182, 2014.

[6] G. Gao, K. Xiao, and M. Chen, "An intelligent IoT-based control and traceability system to forecast and maintain water quality in freshwater fish farms," *Computers and Electronics in Agriculture*, vol. 166, 2019.

[7] B. Shi, V. Sreeram, D. Zhao, S. Duan, and J. Jiang, "A wireless sensor network-based monitoring system for freshwater fishpond aquaculture," *Biosystems Engineering*, vol. 172, pp. 57-66, 2018.

[8] N. Ab. Aziz and K. A. Aziz, "Managing disaster with wireless sensor networks," in *Proc. International Conference on Advanced Communication Technology*, Seoul, South Korea, 2011. pp. 202-207.

[9] M. Alfahadiwy and A. Suliman, "Flood detection using sensor network and notification via SMS and public network," in *Proc. Student Conference on Research and Development*, Uniten, Kajang, Malaysia, 2011, pp. 1-6.

[10] M. A. Nasirudin, U. N. Zabah, and O. Sidek, "Fresh water real-time monitoring system based on wireless sensor network and GSM," in *Proc. IEEE Conference on Open Systems*, Langkawi, Malaysia, 2011, pp. 354-357.

[11] A. Al-Mamun, N. Ahmed, N. Ahamed, S. M. Rahman, B. Ahmad, and K. Sundaraj, "Use of wireless sensor and microcontroller to develop water-level monitoring system," *Indian Journal of Science and Technology*, vol. 7, no. 9, pp. 1325–1330, 2014.

[12] T. Perumal, M. N. Sulaiman, and C. Y. Leong, "Internet of Things (IoT) enabled water monitoring system," in *Proc. IEEE 4th Global Conference on Consumer Electronics (GCCE)*, Osaka, Japan, 2015, pp. 86-87.

[13] J. Šaliga, M. Žiga, P. Galajda, M. Drutarovský, D. Kocur, and L. Maceková, *Wireless Sensor Network for Water Quality Monitoring, XXI IMEKO World Congress: Measurement in Research and Industry*, Prague, Czech Republic, 2015, pp. 1-6.

[14] T. Srited, K. Jaruwongrungsee, and P. Kocharoen, "Wireless sensor network for flash flood warning: Nampung-forested watershed," in *Proc. 30th International Technical Conference on Circuits/Systems, Computers and Communications*, Seoul, South Korea, 2015, pp. 1-4.

[15] M. Z. Mohd. Rodzi, M. N. Ahmad, N. H. Zakaria, and M. I. M. Ismail, "Flood sensor development with ontology-based knowledge integration using design science research methodology," in *Proc. Twenty First Pacific Asia Conference on Information Systems*, Langkawi, Malaysia, 2017, p. 204.

[16] W. M. Shah, A. Shahrin, and A. Hassan, "The implementation of an IoT-based flood alert system," *International Journal of Advanced Computer Science and Applications*, vol. 9, no. 11, 2018.

[17] M. I. Mohamed, W. Y. Wu, and M. Moniri, "Power harvesting for smart sensor networks in monitoring water distribution system," in *Proc. International Conference on Networking, Sensing and Control*, Delft, Netherlands, 2011, pp. 393-398.

[18] F. Shaikh and S. Zeadally, "Energy harvesting in wireless sensor networks: A comprehensive review," *Renewable and Sustainable Energy Reviews*, vol. 55, pp. 1041–1054, 2016.

[19] M. B. Tayahi, B. Johnson, M. Hotzma, and G. Cadet, "Piezoelectric materials for powering wireless remote sensors," in *Proc. 24th IEEE International Performance, Computing, and Communications Conference*, 2005.pp. 383-386.

[20] O. Bjorkqvist, O. Dahlberg, G. Silver, C. Kolitsidas, O. Quevedo-Teruel, and B. Jonsson, "Wireless sensor network utilizing radio-frequency energy harvesting for smart building applications [Education Corner]," *IEEE Antennas and Propagation Magazine*, vol. 60, no. 5, pp. 124–136, 2018.

[21] W. K. Lee, S. J. Q. Ho, and M. Schubert, "Multi-source energy harvesting and storage for floating wireless sensor network nodes with long range communication capability," *IEEE Transactions on Industry Applications*, vol. 54, no. 3, pp. 2606-2615, May-June 2018.

[22] A. S. Adila, A. Husam, and G. Husi, "Towards the self-powered Internet of Things (IoT) by energy harvesting: Trends and technologies for green IoT," in *Proc. 2nd International Symposium on Small-scale Intelligent Manufacturing Systems (SIMS)*, Cavan, 2018, pp. 1-5.

[23] L. Mateu and F. Moll, "Review of energy harvesting techniques and applications for microelectronics (Keynote Address)," in *Proc. SPIE 5837, VLSI Circuits and Systems II*, 2005.