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Energy Harvesting Based on Living Plants For Smart Farming

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ABSTRACT

This paper presents the bio-generator method for smart farming. Energy harvesting (EH) from the natural environment is becoming widely introduced as a sustainable energy source. Nowadays, smart devices for IoT are critically needed to have an EH type of power supply for continuity of sensing changes. The EH presented in this paper consists of two parts: 1) EH as a supply for sensor nodes for WSNs 2) EH as a sensing module for monitoring soil conditions. The principle of EH is based on the PMFC principle. To evaluate the proposed idea, experiments with avocado trees under different conditions were performed. The harvestable voltage ranges from 0.37 to 0.65 Volts, and the voltage can be converted up to 3.12 Volts using a BQ25504 boost converter. The output voltage of the boost converter is sufficient to supply a sensor node in WSN applications.

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1. INTRODUCTION

The concept of the Internet of Things (IoT) has changed the traditional way of human life into a modern society. Smart city smart home pollution control smart transport occurring at present is the tangible paradigm of Transformation by IoT (Kumar *et al*., 2019). IoT uses smart devices, and the Internet provides smart solutions. IoT is behind a wide range of innovations leading to a more advanced lifestyle than ever before. With the ability of the Internet of Things to connect the physical and digital worlds, IoT presents a great opportunity for businesses to transform the traditional way of working into a work style, "state-of-the-art". The connected feature of the Internet of Things gives innovators the ability to create the value of information for their stakeholders (Seetharaman *et al*., 2017).

For environment, security, and process monitoring tasks. Wireless sensor networks (WSN) are presented as a very attractive solution. An example of a solution with a networked wireless sensor. Project Agro has installed a network of wireless sensors for monitoring ocean temperature and salinity, where sensors are deployed to a depth of 2000 meters and can be raised to the top to transmit signals at certain times by transmission to satellite (Gilbert *et al*., 2008).

Monitoring of any target changes, whether the target is stationary or in motion. Where the area is large, WSN is very suitable. But the challenge of WSN design is not only designing the communication algorithm but also considering the stability of the power supply for each node of the WSN as well. The electrical consumption level of network wireless sensors is divided into two modes: active mode and sleep mode. Even when in sleep mode, each node of the network wireless sensor consumes a small amount of electricity, consuming microamperes. The challenge, however, is that each node must be supplied with voltage to each node to be ready to be back in active mode when the monitoring target arrives. Energy harvesting technology is very essential for networked wireless sensors. There is currently extensive research in the development of energy harvesting technologies from natural sources such as solar, wind, and vibration. These natural energy sources are extremely sustainable and non-polluting (Zheng *et al*., 2015).

In 2012, a wearable power generator was developed that aims to be a portable energy harvester and a small, personal electronic device. Researchers synthesize lead-titanium textiles intending to be flexible. The results of the experiment showed that the wearable generator developed can supply voltage up to 6 Volts at 45 nA. The energy generated by this nano wearable generator has enough power to supply the liquid crystal display and UV sensor (Wu *et al*., 2012).

In addition to harvesting electricity from the natural environment such as sunlight, wind, vibration, harvesting electrical energy can also be based on chemical transformations from living plants. In 2008 researchers studied energy harvesting as the electric potential difference between the stems of plants and the soil at the base of the plants. Plants are known to carry water and nutrients from roots to stomata for photosynthesis. Xylems are constantly changing, and in experiments, we were able to harvest voltages in the range of 50-200 millivolts (Love *et al*., 2008). Harvesting electrical energy from trunks and soil has been proposed by researchers as a supply for networked wireless sensors. It uses the temperature difference in the trunk and trunk surface and then uses a thermoelectric to convert this temperature into electrical energy. The voltage range at this method is from 25 mV to 35 mV. A step-up converter is used to convert low voltage. These can be fed to the microcontroller or charged to the battery (Souza *et al*., 2016). In 2017, researchers conducted a study on energy harvesting from tree-covered university campuses. The study compared three types

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of areas. From the experiment, it was found that the electricity generated from living trees in the university's parking area can be a source of electricity for the lighting system (Lee *et al*., 2016). The challenge of harvesting electrical energy from living plants is that the amount of voltage harvested is relatively low in millivolts. This is certainly not enough to supply the wireless sensor network. microcontroller or charge to the battery Researchers has developed a converter capable of converting millivolts to more than 3 volts so that they can be used with networked wireless sensors (Weng et al., 2013).

This paper presents energy harvesting (EV) from living plants to be a power supply for connected devices for the IoT concept. In addition, the EV principle has been introduced as a built-in sensor for sensing environmental change around the plant root. According to the principle of EV, this paper applies Plant-Microbial Fuel Cell (P-MFC) to achieve energy harvesting. In the experiment, the copper (Cu) and aluminum (Al) electrodes have been tested to harvest the small amount of voltage level in the range of mV. Finally, the boost converter BQ25504 is tested with the EV generated by the living plant.

2. METHODS

The concept of energy harvesting from living plants for this article is based on a principle known as bioelectric production. There are several types of bioelectric, and in this paper, they are presented as fuel cells, in which the cell contains plant-microbial at the roots of plants. The generation of electrical power in this manner is known as Plant-Microbial Fuel Cell (P-MFC). Naturally, soil microorganisms carry out their activities around them. living plant roots in soils without viable plant roots, microbial activity was up to 10 times less. Considering the relationship between plant roots and soil organic matter was released by plants and oxidized by the bacteria there. In PMFC, bacteria decompose organic matter and release electrons to the MFC anode rods. The more complex the mix of planting material, the more difficult it is to assess its oxidization. Oxidization for the acetate by bacteria model is shown in (1). The equation for determining the cathode reaction is shown in (2). The total voltage that can be generated from the P-MFC can be calculated from the Nernst potential of the anode and cathode as shown in (3). The total amount of electricity that can be obtained from the P-MFC is determined by two factors: voltage and current. The product of the voltage and current leads to the power output of the system. The avocado tree was chosen for this experiment because of its strong root system and rapid development. It is also a plant whose root and leaf systems are relatively closely related, allowing experiments to be carried out over a longer period than typical herbaceous plants. **Figure 1(a)** shows the avocado seed after it has sprouted. Usually takes about 30 days from seed sowing. **Figure 1(b)** shows the root system of an avocado approximately 3 months old from seed germination, and **Figure 1(c)** shows an avocado with the anode and cathode electrodes in the plant pot.

$$CH_3COO^- + 4H_2O \rightarrow 2HCO_3^- + 9H^+ + 8e^- \quad (1)$$

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \quad (2)$$

$$E_{an} = E_{an}^0 - \frac{RT}{8F} ln\left(\frac{[CH_3COO^-]}{[H^+]^9[HCO_3^-]^2}\right) \quad (3)$$

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Figure 1. Plant preparation for EH based on living plant
(a)Avocado seed, soil, and plastic pot (b) Avocado root system (c) Avocado plant with anode and cathode electrodes.

The energy harvesting (EH) in this paper consists of two parts: EH as a power source for a sensor node in WSNs and EH for the perception of changes in root and soil regions. **Figure 2** illustrates an EH concept based on the P-MFC principle. The electrical energy harvesting electrodes for the supply source for the sensor node are represented by the symbols A1 and K1, while the plant change sensing electrodes are represented by the symbols A2 and K2 where A and K represent the meaning of the anode and cathode respectively. In the case of electrode materials. copper and aluminum wire were used to design as the anode (A) and cathode (K), respectively.

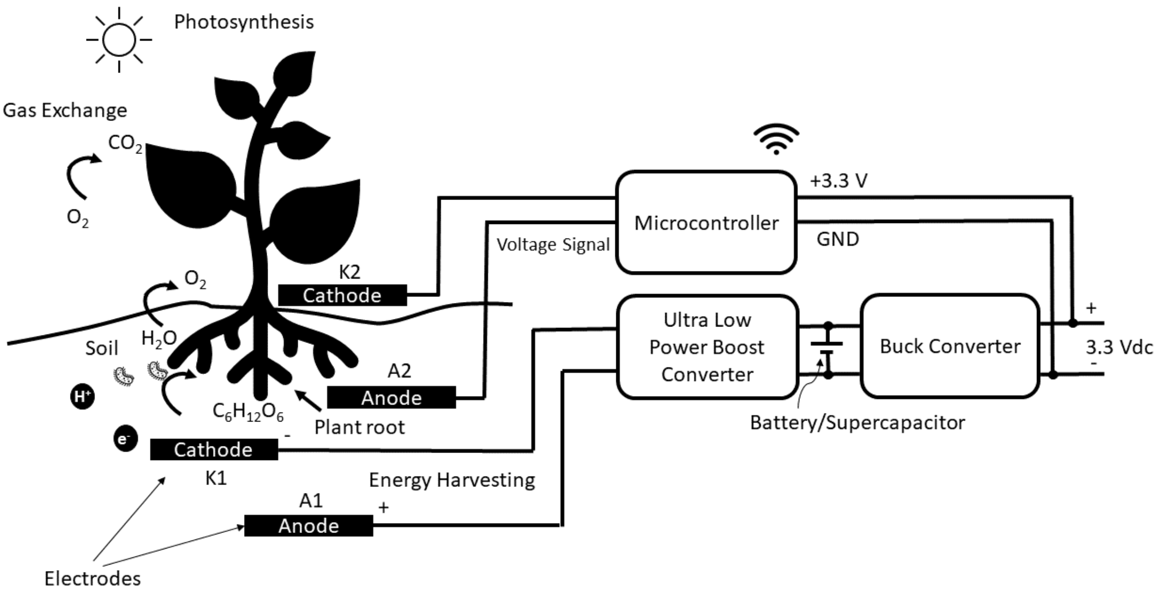

Figure 2. Concept diagram of the proposed EH method.

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The A1 and K1 series of electrodes, which harvest electrical energy from the foregoing bioelectric reaction, are fed to the low voltage converter unit (in range of mV) into the voltage that the microcontroller can operate which is usually around 3.3 volts. For the A2 and K2 electrode kits, it is a kit for perceiving changes in plants. Note that the K2 electrode must be placed on the surface of the soil since the surface location is where physical changes in the soil can be perceived. For example, the soil is moist, the change signal from the A2 and K2 electrodes in the form of voltage will be interfaced with the microcontroller on the analogy port.

Figure 3 shows a diagram of a transformed converter (BQ25504) designed by Texas Instrument. The specialty of this controller is that it can convert a low input voltage to a high enough voltage to be supplied to the microcontroller. For IoT or WSNs, BQ 2504 is widely used for energy harvesting using solar panels or thermoelectrics. However, the application of BQ 25504 for P-MFC applications is not yet presented. Potential differences harvested from natural sources such as solar cells, thermoelectric, etc. are fed to BQ2504 via pins 16 and 2 as shown in **Figure 3**, where they are to be in series with the inductor as shown. Voltage divider resistors can be selected according to the designer's requirements. According to the company's specs, BQ2004 can convert a minimum voltage of 130 millivolts, which is ideal for harvesting natural energy that is, in principle, low-voltage electrical power.

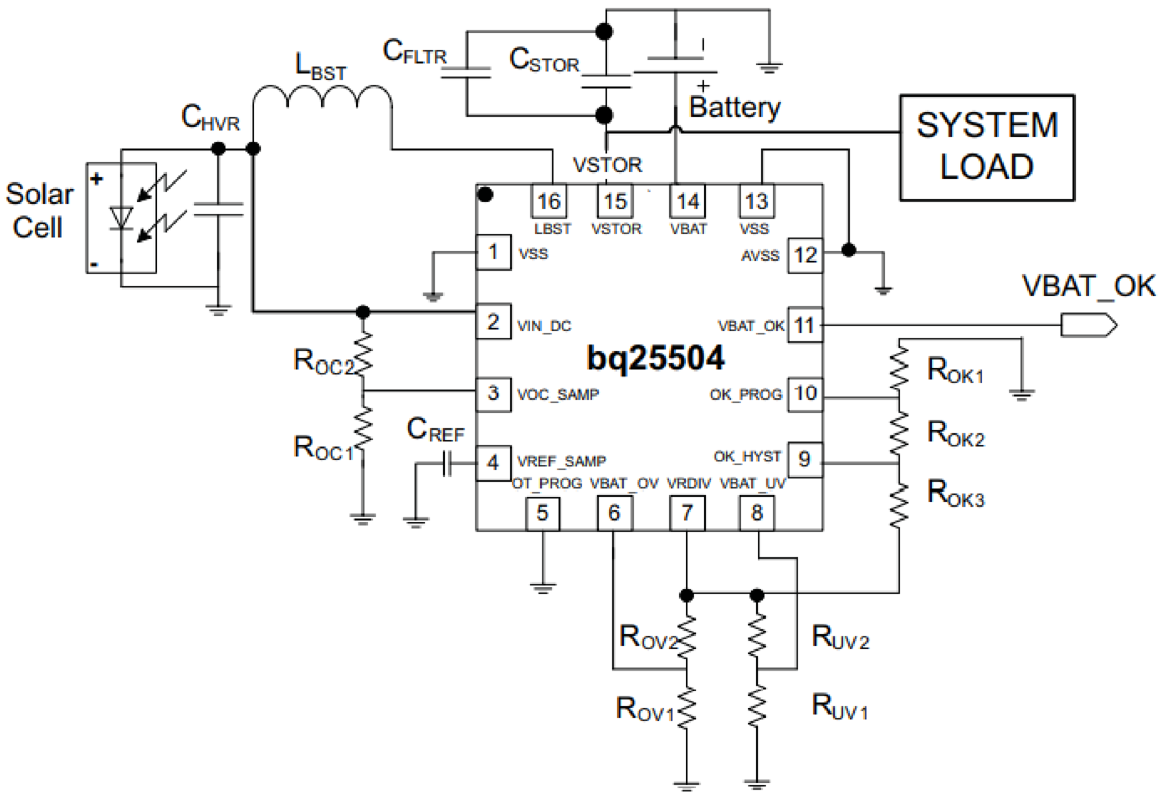

Figure 3. Ultra-low-power boost converter circuit using BQ25504.

3. RESULTS

According to the proposed idea of harvesting energy from living plants, the avocado tree would be used throughout this paper. The experiments were divided into 2 sections. 1. An experiment to measure the harvested voltage from different conditions. 2. An experiment to convert the harvested pressure.

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3.1. Measurement of Energy Harvesting Voltage

This first experiment proved the voltage that can be harvested from live plants using the P-MFC principle with clay pot size 0.2m x 0.3m x 0.4m in width long and high, respectively. A total of 4 copper electrodes and 6 aluminum electrodes were installed inside the pot as shown in **Figure 4**. The experiment was divided into 3 sub-experiments: 1) the soil pot without the living plant, 2) the soil pot with the living plant, and 3) The soil pot with the living plant for 1 month.

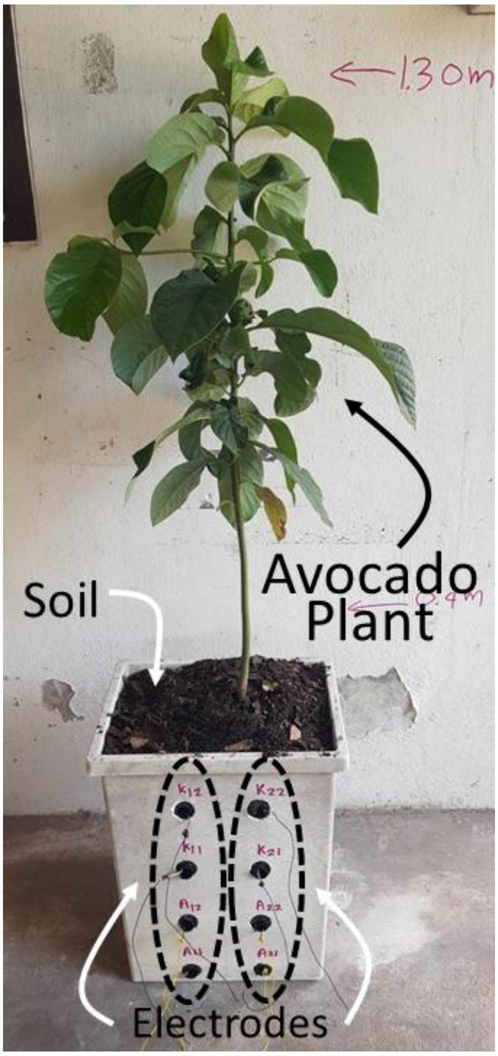

Figure 4. Avocado plant for energy harvesting experiment.

From the experiment, the voltage harvested from the pair of electrodes was measured in the range 0.37-0.65 V as shown in **Figure 5**. For cases where both A and K electrode pairs were in the soil beneath the roots as shown in Figure 6, the experiments showed that avocado roots resulted in a higher voltage harvest than the experiment without the avocado plant. or just starting an avocado tree. The maximum harvesting voltage is 0.65 Volts.

Voltage harvesting at A11 and KTOP electrode pairs found that the voltage changes in the range 0.4-0.65V and 0.4-0.66V for the experiments in **Figure 5** and **Figure 6**, respectively. This experiment shows that the harvested voltage can not only be used as a power supply to the microcontroller but can also be applied to Push the electrode pair at the right position to sense the changes of the plants.

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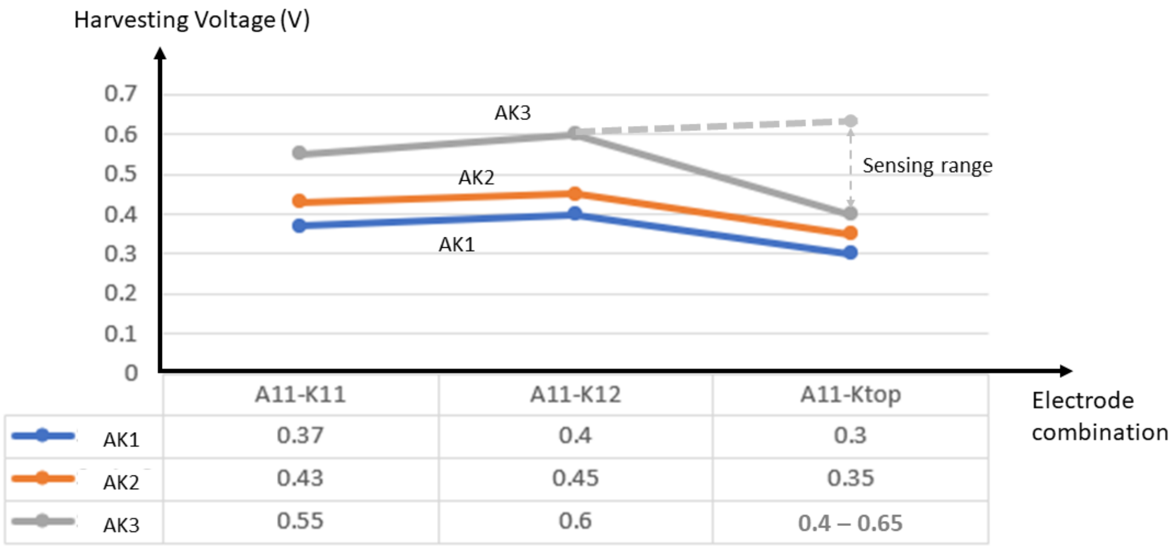

Figure 5. Measurement of energy harvesting voltage A11-K11, A11-K12 and A11-Ktop.

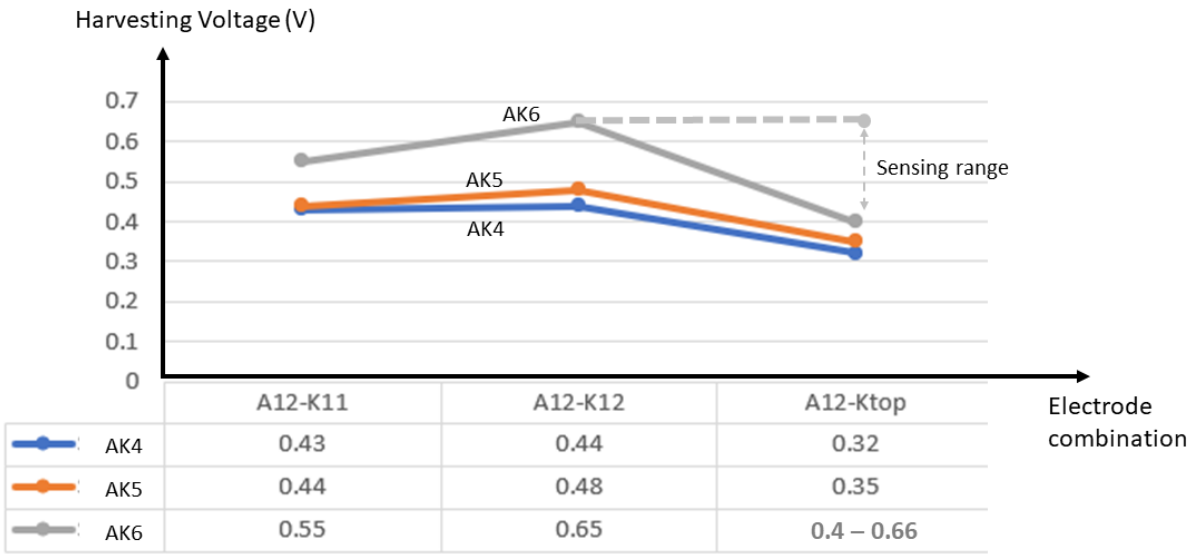

Figure 6. Measurement of energy harvesting voltage A21-K11, A12-K12 and A12-Ktop.

3.2. Boosting of Energy Harvesting

As shown in section 3.1, the first experiment was to measure the voltage harvested from electrodes from live plants. The harvested voltage ranges from 0.37-0.65 volts. Although, this voltage is sustainable as it is naturally harvested in green energy. However, this low-level voltage is not enough to supply the microcontroller with power. This experiment is to convert a naturally harvested low voltage to 3.3 Volts to supply a microcontroller for IoT or WSNs.

Figure 7 shows the preparation of tools and equipment used for the experiment, including avocado plant pots, pot soil, AK electrodes, Grow light lamp for simulating plant photosynthesis conditions, Boost Converter Module (BQ25504), Oscilloscope. The voltage from the oscilloscope is shown in **Figure 8**. BQ25504 can boost the voltage from the voltage harvested from a pair of 0.65 Volts (650 mV) to 3.12 Volts. This level of voltage is sufficient to be a power supply for a sensor node in WSNs.

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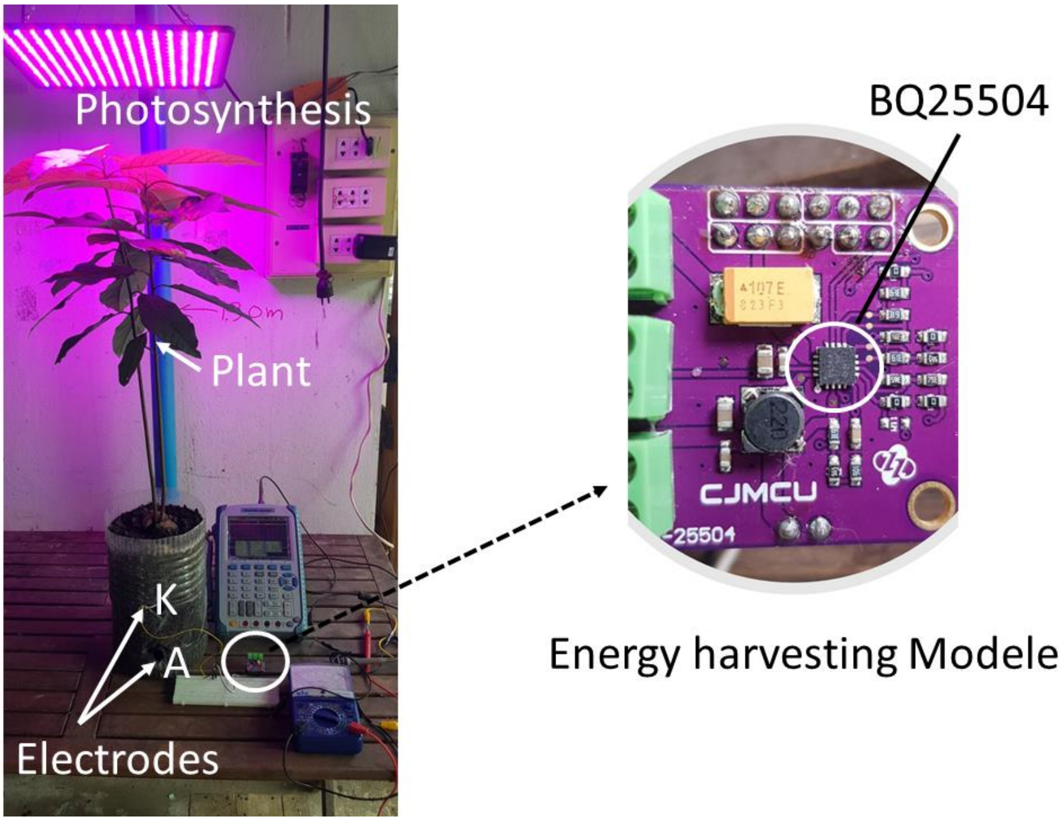

Figure 7. Step-up harvesting voltage using BQ25504.

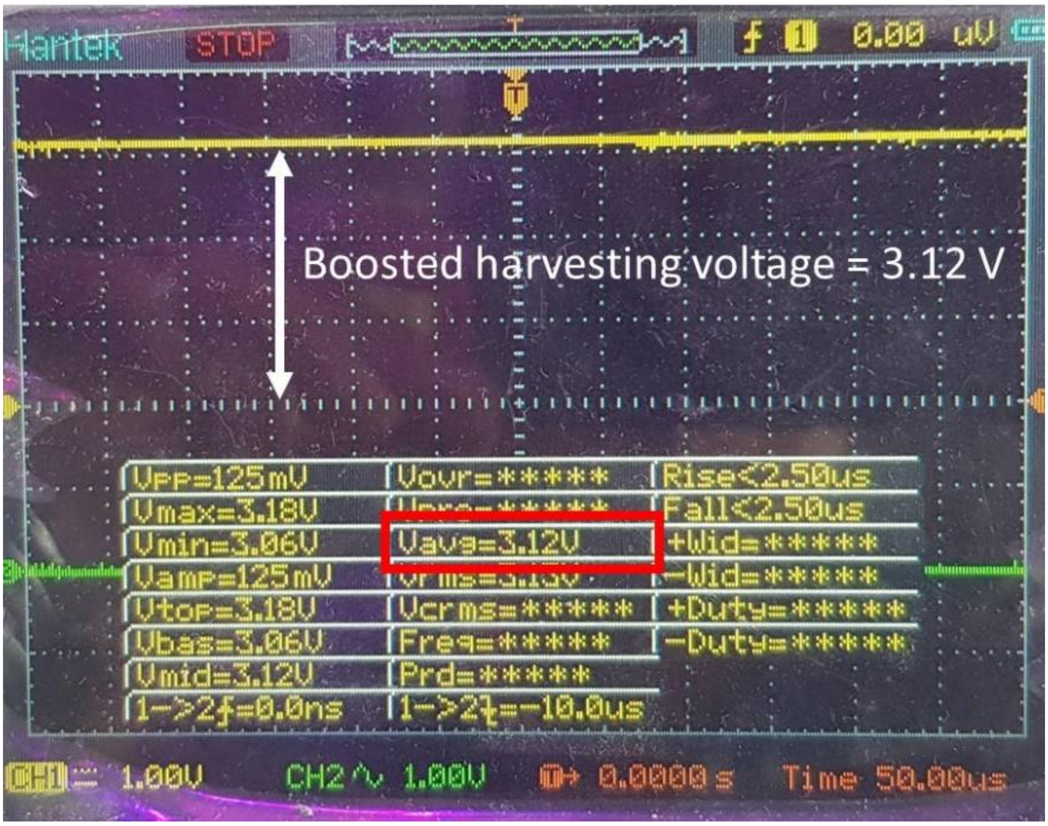

Figure 8. The output voltage of Boost converter BQ25504.

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4. DISCUSSION

The experiments show the proposed concept of both harvesting electricity for supplying sensor nodes for IoT and at the same time being able to perceive changes in soil conditions at the root area as well. However, the voltage obtained from the Boost Converter BQ25504 is approximately 3.12 Volts, which in the design aims to provide a voltage of 3.3 Volts. A tolerance of approximately 0.18 Volts is likely due to the size of the electrodes. From the experiment, the author conducted a series of paired electrodes in the same pot. to simulate the situation as if connecting batteries in series. The voltage obtained from two pairs of electrodes in series is not equal to double the voltage obtained from a single pair of electrodes. The energy harvesting from pairs of electrodes, if wanted to be connected in series, should be separate pots to achieve the desired voltage level.

5. CONCLUSION

This paper presents electric power harvesting from live plants for smart farm applications. The results of the experiment proved that the PMFC principle can harvest electrical energy at a maximum voltage of 0.65 millivolts and can be boosted with a BQ 25504 boost converter. The voltage rises to 3.12 volts, which is sufficient to supply a sensor node in WSN. In addition to that, the proposed concept can also sense the change in the soil moisture environment with another pair of electrodes. This makes it very cost-effective to manage the power supplied to WSN.

6. ACKNOWLEDGEMENTS

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7. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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