Evolution in Electrical and Electronic Engineering Vol. 3 No. 2 (2022) 888-894

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Piezoelectric Shoe Energy Harvesting with IoT Monitoring System

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DOI: https://doi.org/10.30880/eeee.2022.03.02.104
Received 27 June 2022; Accepted 04 October 2022; Available online 30 October 2022

Abstract: This paper focuses on harvesting mechanical energy from human motion as an appealing method of getting clean and sustainable electric energy using wearable piezoelectric shoes. However, the main concern is charging the phone on the leg while walking or jogging will interfere with the user's activities and no storage or protection system is developed to use piezoelectric electricity efficiently. Thus, in this paper, a piezoelectric shoe energy-harvesting prototype consisting of a battery management system monitored by an Internet of Things (IoT) platform is developed. The developed system can charge the battery through a battery protection module while discharging at 5V and 2A to charge a mobile phone. The method of the project uses an Arduino Wemos ESP8266 D1 R2 as a microcontroller to transfer data through IoT with the input from a piezoelectric ceramic sensor. The AC input from the piezoelectric sensor is converted to DC by a bridge rectifier and DC input is smoothed by a capacitor before entering the battery management system. Battery charging time depends on battery capacity and input current from the piezoelectric sensor. It is concluded that the prototype manages to monitor a battery management system through an IoT platform and charge a mobile phone. A further possible attempt needs a fuel-gauge sensor to accurately read the voltage and percentage of the battery while a set of high-quality piezoelectric sensors is needed to charge the battery efficiently.

Keywords: Energy-Harvesting, Piezoelectric Ceramic Sensor, IoT Platform

1. Introduction

Renewable energy is obtained via natural processes that are continually renewed. Every day, many people walk, jog, and run, generating tremendous amounts of energy that are wasted. The compression and bending of the shoe sole indicate a means to collect energy that may be used for beneficial purposes. Furthermore, from previous works of the piezoelectric shoe, due to the apparent weight of the phone on the user's feet, charging the phone on the leg while walking or jogging will interfere with their activities which is not an efficient way to utilize this piezoelectric shoe. In addition, no storage and protection system is developed to use piezoelectric electricity efficiently [1]. Thus, in this project, Battery

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Management System (BMS) was built to monitor the battery charging/discharging status along with battery voltage and percentage. As a result, keeping an eye on the battery's voltage level is critical, as improper or excessive charging/discharging can damage the battery or cause system failure. A distinct mechanism known as the BMS is found in most electrical/electronic devices [2].

A piezoelectric sensor or transducer is a device that converts changes in pressure, acceleration, temperature, strain, or force into an electrical charge via the piezoelectric effect [3]. The piezoelectric effect is the ability of a piezoelectric substance to transform mechanical stress into an electrical charge. The amount of piezoelectricity generated is proportional to the amount of pressure applied to solid piezoelectric crystal materials [4]. In this paper, a voltage supply of 4.5V DC must be produced from the piezoelectric device, where mechanical pressure from the user's footstep directed to the piezoelectric is converted from AC to DC to power up the battery charging-discharging protection module [5].

According to their crystal structure, piezoelectric ceramics are divided into four groups: perovskite structure, tungsten bronze structure, bismuth layer structure, and pyrochlore structure. Nonetheless, there is an alternate classification scheme [6]-[7] based on distinct fundamental components. Other system ceramics include unit system ceramics, binary system ceramics, ternary system ceramics, and quaternary system ceramics. Due to their varied applications, PZT4i-PZT8i (or P4i-P8i, I = 1, 2, 3, etc.) are now the most popular designations for piezoelectric ceramics on the market. P4 is utilized to transmit and receive signals. P5 is mostly employed for driving and detecting. P6 signifies good stability. P7 is an abbreviation for high frequency and Lead zirconate titanate [8].

The actual design of the piezoelectric shoe energy harvesting and battery management system is expected to be produced at the end of this paper. It also covered the setup on the IoT platform using an Arduino Wemos ESP8266 D1 R2 as a microcontroller to observe battery voltage and percentage. The value of voltage and percentage obtained are also displayed on IoT by measuring and observing them in the coding created.

2. Methodology

The prototype circuit is categorized into two, integrating input supply and BMS. The integrating input supply consists of a piezoelectric ceramic and film sensor, KBP307 bridge rectifier and 10μF capacitor. While the BMS consists of a 18650 lithium battery charging-discharging integrated module, 3.7V 1300mAH lithium-ion battery, 100k resistor and Arduino Wemos ESP8266 D1 R2. To display output voltage and percentage of battery, Arduino Wemos ESP8266 D1 R2 is used to connect data through the Thingspeak IoT platform. Specifications and properties of materials and equipment used in the project are described in Table 1 [9].

Table 1: Specifications and properties of equipment used in the project

Equipment	Function
Piezoelectric ceramic and film sensor	Create electricity upon mechanical force
KBP307 Bridge Rectifier	Convert AC voltage to DC voltage
10μF Capacitor	Smoothen the DC voltage output
18650 Lithium Battery Charging Discharge Integrated Module	Charging the battery while providing protection and discharging the battery
3.7V 1300mAH Lithium-Ion Battery	Energy storage
100k Resistor	Lowering voltage to enter Arduino
Arduino Wemos ESP8266 D1 R2	Connect Thingspeak IoT via WIFI connection

The block diagram for the piezoelectric shoe energy harvesting with BMS is shown in Figures 1 and Figure 2. Several types of piezoelectric are used to obtain 4.5 V DC to operate the battery charging module. First, AC voltage from the piezoelectric circuit is converted to DC voltage through the bridge rectifier. The DC voltage then goes to the capacitor, which reduces the ripple by converting the ripple voltage into a smoother DC voltage. At these points, the battery charging module needs 4.5 V DC to operate and start charging the 3.7 V Rechargeable Li-ion Battery. At the output from the battery charging module, a female USB port will be attached for charging the phone, etc. The battery's maximum voltage is 4.2V, with a voltage cut-off of 2.8V. Before entering Arduino, a 100k resistor is used as a voltage divider because anything lesser than 3.3V will be easily supported by the ESP8266 Analog Pin. Lastly, a setup coding on Arduino IDE is needed to produce voltage and battery percentages output to show on the IoT platform. Furthermore, Figure 3 shows the connection of piezoelectric shoe energy harvesting with an IoT monitoring system where the piezoelectric sensor is connected in parallel and then connected bridge rectifier and capacitor. On the charging module, there are an input terminal, battery charging terminal and discharge terminal. Next, the module was connected to a pair of 100k resistors a voltage divider and connected to an Arduino microcontroller.

Figure 1: Block diagram for Piezoelectric Shoe Energy Harvesting Integrating Input Supply

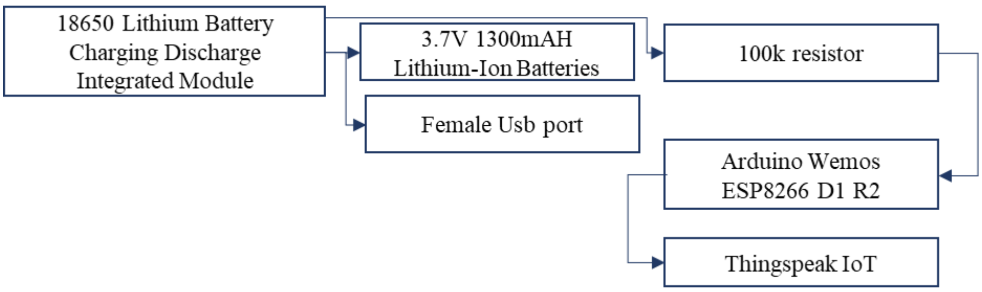

Figure 2: Block diagram for Battery Management System (BMS)

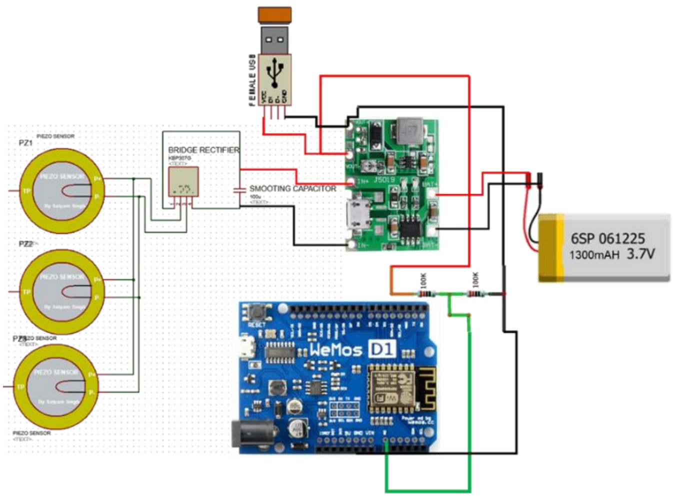

Figure 3: Connection of Piezoelectric Shoe Energy Harvesting with IoT Monitoring System

Figure 4 shows the configuration on Thingspeak to monitor the battery data on the server at https://thingspeak.com/. First, an account must be created or simply log in to the MATLAB account. There are two fields created, where to display the graph on battery voltage and percentage as part of the battery management system. Based on Figure 4 shows the API key which is a code used to identify and authenticate an application or user. It acts as a unique identifier and provides a secret token for authentication purposes. Thus, the API key is needed to include in the coding to be able for coding connect with WFI and Arduino.

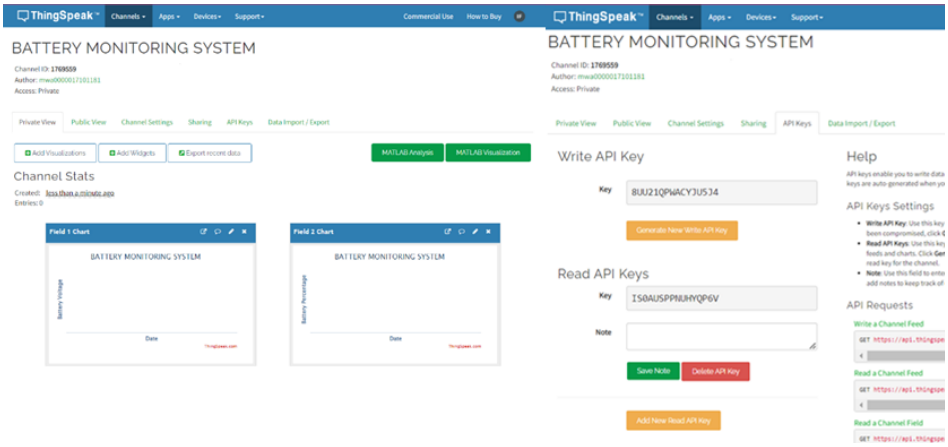

Figure 4: Configuration on Thingspeak

To understand how the Arduino Wemos ESP8266 can connect to the WIFI mobile phone and link to the Thingspeak platform. Coding on Arduino IDE is complicated but can be explained simply through a flow chart, as shown in Figure 5. The battery voltage and percentage loop and displayed on the serial monitor. Based on the battery cut-off, 2.5V to 3.0V will be around 1 to 50 percent, 3.0V to 3.7V approximately 50 to 80 percent and 4.0V to 4.2V around 80 to 100 percent.

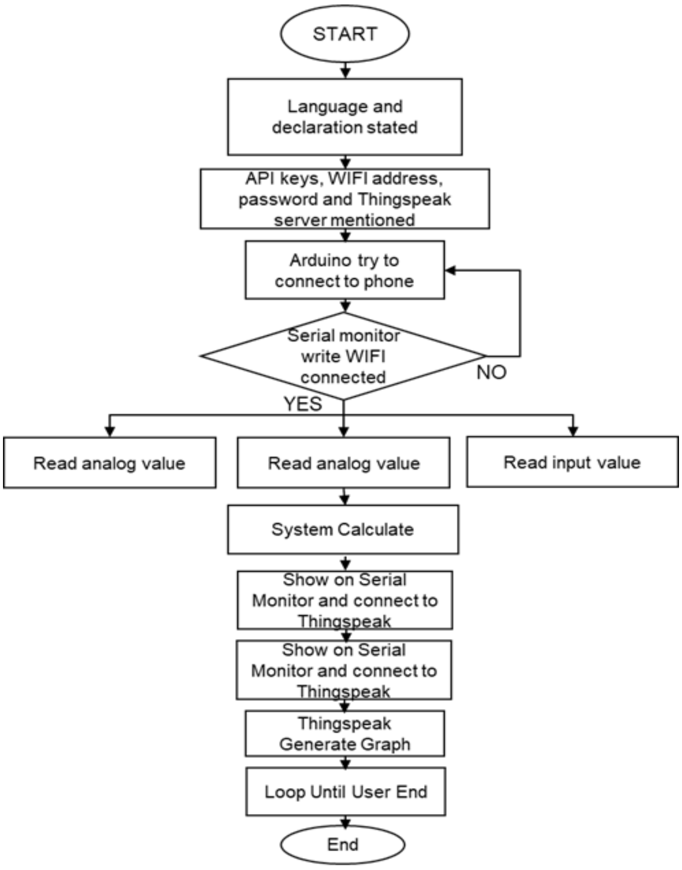

Figure 5: Flowchart on coding

3. Results and Discussion

The circuit can be successfully designed for charging the battery as the bridge rectifier converts the AC voltage to DC voltage and smoothens it by the capacitor before entering the battery module. Figure 6 shows the final prototype design. The piezoelectric insole can generate 0.5V to 13V voltage, where successfully for 18650 Lithium battery charging discharge integrated module to be operated at 4.5V. The red LED on the battery module blinking indicates the charging is successfully operated. The battery voltage and percentage loop and displayed on the serial monitor as shown in Figure 7. Thus, the serial monitor is sent to Thingspeak to create battery voltage and percentage as shown in Figure 8.

Figure 6: Final prototype design

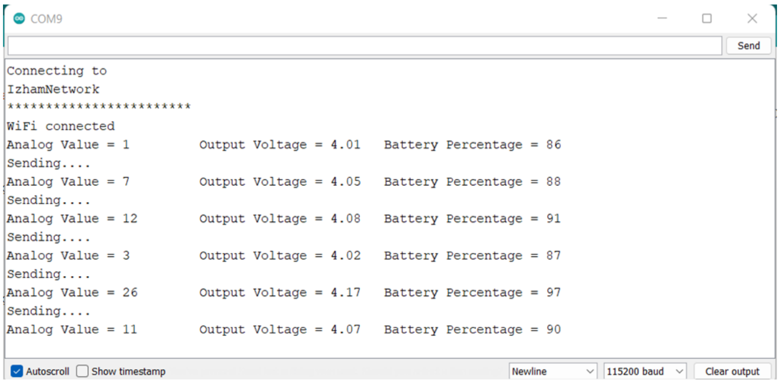

Figure 7: Serial monitor

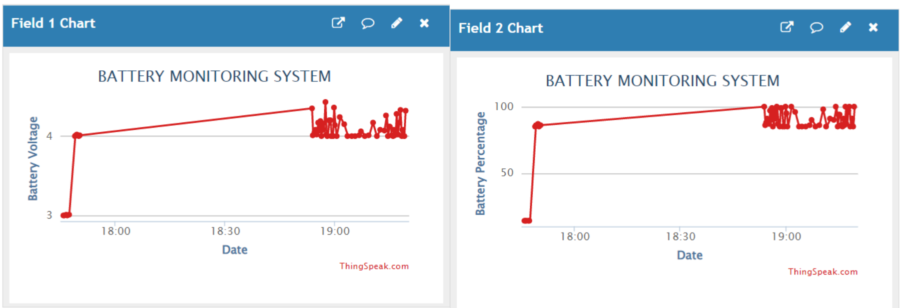

Figure 8: The Graph of Voltage and Battery Percentage on Field 1 and Field 2 on Battery Monitoring System Channel

Depending on losses, the 18650 Lithium battery integrated module is adjusted to discharge 5V and 2A maximum. The module starts to head up when the USB is plugged into the female USB port. The current mobile phone is being measured using an Application from Google Play Store named Ampere. Figure 9 shows Ampere Apps measuring current from the 18650 Lithium Battery Integrated Module to the mobile phone and next, the phone is in charging the state with 1160mA.

Figure 9: Ampere Apps measuring current from the 18650 Lithium Battery Integrated Module to the mobile phone

For the battery to be fully charged, it can be estimated through calculation from input current from a piezoelectric device and based on the capacity of the lithium-ion battery. Before that, it was difficult to obtain a current reading with a multimeter, so impedance reading was measured thus an equation of Ω= V/A or R= V/I was used. Maximum voltage and impedance used in the equation:

$$I = \frac{V}{R}$$

$$I = \frac{13V}{6.22M\Omega}$$

$$I = 2.09\mu A$$

$$\text{Battery charging time (hour)} = \frac{\text{Battery capacity (In Ah)}}{\text{Current supplied (In A)}}$$

$$\text{Battery charging time (hour)} = \frac{\text{1300m (In Ah)}}{\text{2.09}\mu\text{ (In A)}}$$

$$\text{Battery charging time (hour)} = 622.009k\ hour$$

Due to losses in piezoelectric, the current is too low and the charging time is unrealistic for the user to charge the battery. Losses in a piezoelectric material result from the dielectric reaction to an electrical field, the mechanical response to applied stress, its piezoelectric motion, its strain response to the electric field, or, conversely, charge or voltage generation as a result of applied stress. Piezoelectric material losses cause sample heating or noise output [10]. Furthermore, loss mechanism control is required to maximize the effectiveness of this Piezoelectric Shoe.

4. Conclusion

In conclusion, the design of the "Piezoelectric Shoe Energy Harvesting with IoT Monitoring System" is successfully created. The piezoelectric ceramic and film sensor connected in parallel and produced 0.5V to 13V after the conversion from AC to DC by bridge rectifier and the voltage smoothen by the capacitor, able to charge battery charging protection module and achieved objective one. The battery management system was successfully operated via 18650 Lithium Battery Integrated Module through Arduino Wemos ESP8266 D1 R2 and connected to the IoT platform. Therefore, it can be concluded that the Piezoelectric Shoe circuit design fulfils the charging of mobile phones via a female USB port. Last but not least, the recommendation for future work is to design the integrating circuit with better piezoelectric material that can withstand significant mechanical force. Then, a fuel-gauge module and details calculation need to be added to the circuit to measure battery voltage and percentage accurately and add an OLED display for the user-friendly interface.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

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