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Experimental Validation of the Piezoelectric Energy Harvester for Wearable Devices

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Abstract. This paper presents the experimental validation of the piezoelectric array in harvesting the vibration energy from human activity. This experiment is aimed to choose the best array topology of piezoelectric energy harvesting (PEH) for replacing the battery on our wearable devices. Based on our experiments, the no-load characteristic of PZT array shows the big hope for future implementation on wearable devices.

1. Introduction

Energy harvesting device used to collect ambient energy resources and convert those into electrical energy. The most commonly used ambient energy is light, wind, thermal gradients and vibrations [1, 2]. For example [3], Author generates electrical energy from combining piezoelectric and electromagnetic in one unit. They used some topologies to produce electrical energy efficiently from two sources. Author [4] examined nanoscale energy harvesting which resulted in the higher energy by adjusting the surface material

Energy harvesters using piezoelectric are one of the most popular ones. Piezoelectricity can convert vibration energy into electrical energy. Vibration energy provides in surroundings, for example, in mechanical equipment, buildings, roads, railways, and human body [5]. Research in [6] had investigated and updated the Spring-comprised Piezoelectric Energy Generator (SPEG) by varying spring strength and support excitation. In [7], Authored examined the implementation of piezoelectric energy harvesters in the galloping phenomenon. Researchers utilize in aerodynamic instability for energy harvesters. The results of the proposed system show a significant increase compared to the energy harvesting system proposed in the literature.

The existing research on piezoelectric energy harvesting was focused on the piezo material. In this paper, we proposed an experimental validation of piezoelectric energy harvesters for wearable devices. The purpose of this study is to examine the feasibility of PEH for powering the wearable sensors. We conducted several scenarios to choose the best array topologies for our application.

The rest of this paper organized as follow. Section 2 is related works and Section 3 is the Experimental Method. Section 4 and Section 5 describe the Result and Analysis, and Conclusion,



respectively.

2. Related Works

In [8], piezoelectric power generation technology for pavements have two methods: piezoelectric material composite and transducer embedded pavement piezoelectric power generation. Transducer embedded pavement technology for piezoelectric power plants can obtain higher and more controlled power output.

There are three types of mechanical-electric conversion modes in the piezoelectric transducer: d31, d33, and d15. D33 mode comes from vertical compressive pressure, whereas d31 mode electricity is generated from horizontal compressive stress. In the d15 mode, it is rarely used on the pavement because it requires the effect of shear stress to produce electrical energy. The d33 mode has a higher piezoelectric coefficient. Therefore, this study uses the d33 mode of stacked piezoelectric transducers. The wireless sensor is installed on the bridge to ensure the vehicle runs safely and monitors the structural state of the bridge [9-12]. The battery is needed to supply the system, but using a battery has the disadvantage of repeated replacements, very expensive and not feasible in some special situations. This potential use of piezoelectric energy harvesting systems for civil infrastructure is gaining attention [13,14].

One way to harvest vibration energy on bridges is to use piezoelectric. In the study [15], tested the piezoelectric energy harvester from the vehicle bridge vibration. Based on the vibration characteristics of the clutch platform, two piezoelectric energy harvesters (PEHs) with different basic frequencies. PEH-1 is designed with the natural frequency of the bridge and PEH-2 is designed with the vibration frequency of the vehicle-bridge coupling. PEH voltage output was measured in nine different cases and the energy harvesting performance of PEHs was discussed. The results show that the PEH-1 voltage has a peak when the vehicle enters or leaves the bridge and is almost zero when the vehicle moves on the bridge. While the PEH-2 voltage when the vehicle moves on the bridge. Experimental results also show that more energy can be harvested when PEH is installed in the middle of the bridge.

To utilize renewable energy in the transportation sector, research on the application of thermoelectric and piezoelectric effects on the pavement of energy harvest has grown significantly. The study [16] provides a literature review of the application of thermoelectric and piezoelectric to produce electricity on the pavement. In the previous literature, piezoelectric with piezoelectric transducers (PZTs) showed limited amounts of electrical output, while pipe systems that worked with thermoelectric (TEG) generators could produce more electricity. So that on the sidewalk has the potential to harvest energy. The results of a study on the Florida highway, if the entire road network is covered by a proposed system (PP-TEG system) gets 55 GWh of electricity per day, while one covered by PZTs only produces 4.04 MWh of electricity per day. Based on the cost-effectiveness analysis of the two systems, unless the PZT system is only paved in parts of the road with very high traffic volumes, the PP-TEG system is more cost-effective than the PZT system. Compared with the above existing works, our work has two distinction:

- We test the feasibility of the piezoelectric arrays in generating low power electrical energy.
- We measured the vibration rather than force.
- We used the round type of Piezoelectric with diameter 20mm.

3. Experimental method

We conducted experiments for analyzing the feasibility of the piezoelectric (PZT) for harvesting pressure energy from human feet, see in figure 1. This experiment was divided into 2 scenarios: (1) no load test; (2) loading test. In both scenarios, we measured the current and voltage on the output terminal of the bridge rectifier. Each test was applied to 5 PZT arrays as shown in Figure 2. The data collected from 5 samples. That sample has a different gender, weight, and height as shown in Table 1.

Table 1. sample information.

Gender	Age	Height(cm)	Weight(kg)
male	21	166	45
male	21	169	68
male	20	170	55
female	20	155	45
male	20	175	75

Then, the output current and voltage for each experiment is averaged. Besides, we also record the data using an oscilloscope to capture the working frequency of piezoelectric. To meet the requirement for powering the wearable wireless sensors, we used resistors with resistance $100\ \Omega$, and $1\ \text{k}\Omega$. Moreover, we used linear regression for data analysis.

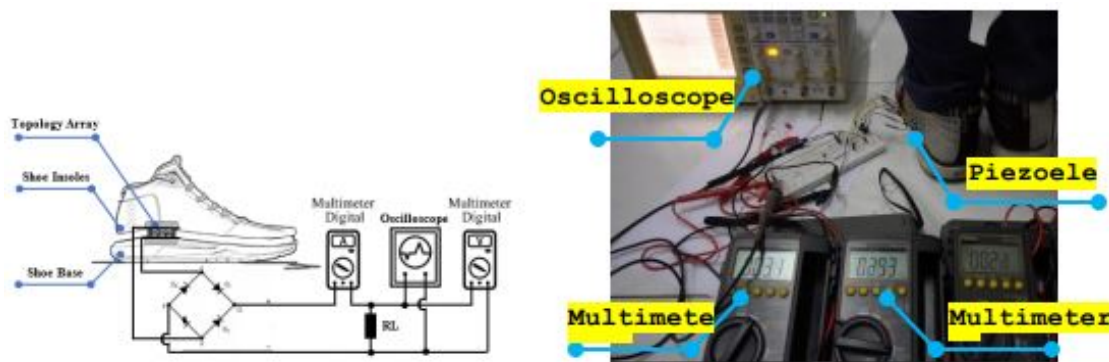


Figure 1. Experiments for analyzing

4. Result and Analysis

Experiments had done and results were collected and plot into graphs. The measurement results for no-load test for all PZT array topologies are shown in Figure 3 and Figure 4. As the vibration increased, the open circuit voltages and short-circuit current are increased, except the PZT array #5 or topology 5.

Figure 5 and Figure 6 depicts the effect of vibration on voltage and current generated by the PZT arrays which loaded by $100\ \Omega$ and $1\ \text{k}\Omega$. As the vibration is increased, then the resulting voltage and current on PZT terminals are increased. The voltage dropped to $0.004925\ \text{V}$ and the current reached $2.9785\ \text{A}$ when the vibration is $1\ \text{m/s}^2$ at a load of $1\ \text{k}\Omega$.

The experimental results regarding the most efficient topology are Topology 5 (PZT array in series-parallel connection). The topology 1 (single PZT) draw a current value of $3.033\ \text{mA}$, a voltage value of $0.00184\ \text{V}$ and a power value of $0.005581\ \text{mW}$ as depicted in Figure 7.

Figure 8 depicts the result of the topology 2 that is PZT array in series connection. The current value generated by this array is $1.4166\ \text{mA}$, the voltage is $0.00843\ \text{V}$ and the power is reached to $0.011942\ \text{mW}$. Figure 9 shows the current value of $3.075\ \text{mA}$, the voltage value of $0.002045\ \text{V}$ and the power value of $0.006288\ \text{mW}$.

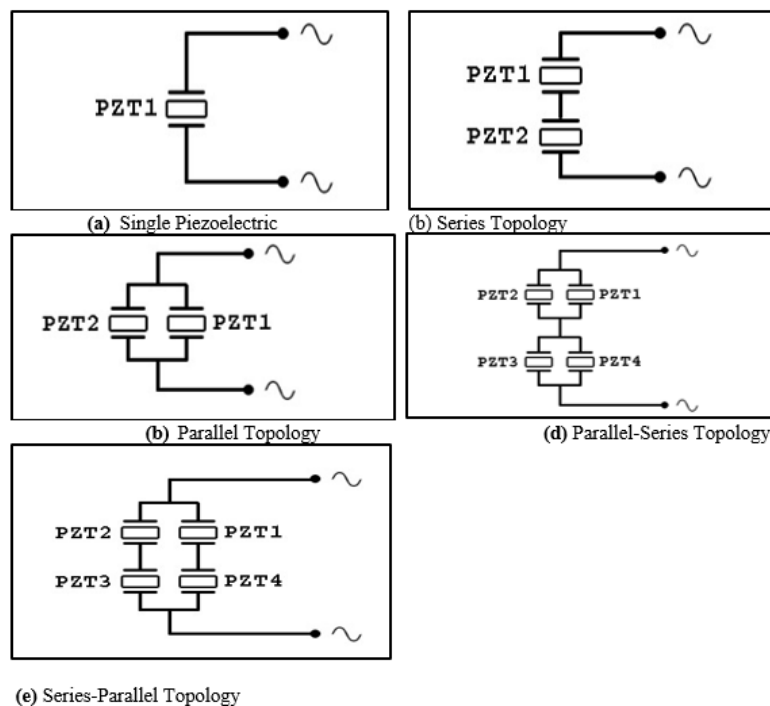
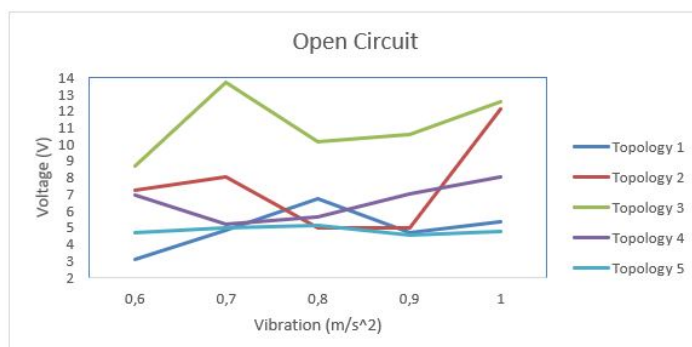
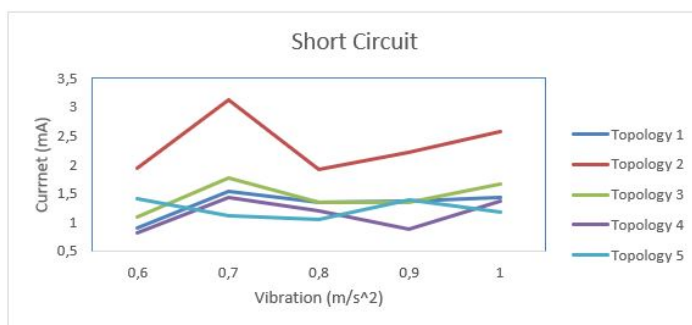
**Figure 2.** Pizoelectric Array.**Figure 3.** Open circuit Voltage.**Figure 4.** Short Circuit Current.

Figure 10 shows measurement results for topology 3 where 2 PZTs connected in parallel. The $1\text{ k}\Omega$ load was drawn current for about 2.9785mA when the output voltage is 0.004925V . Thus, the generated power by this PZT array is 0.014669mW . Figure 11 shows the output current, the output voltage, and the power value of the PZT array 4 are 2.166mA , 0.00257V , and 0.005567mW , respectively.

Based on the obtained results, the best array PZT is 4 PZTs connected in series and parallel.

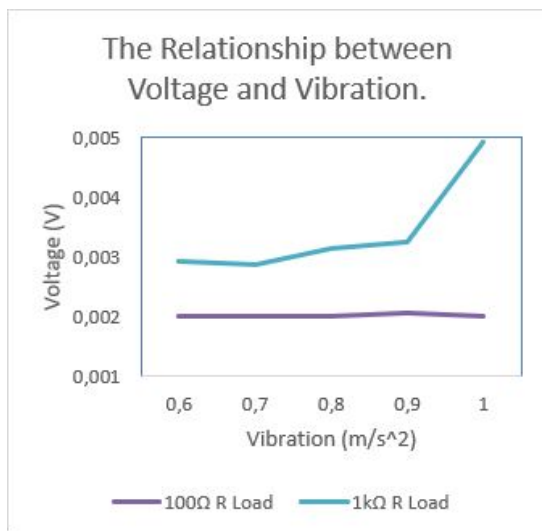


Figure 5. Graph of Voltage with Vibration.

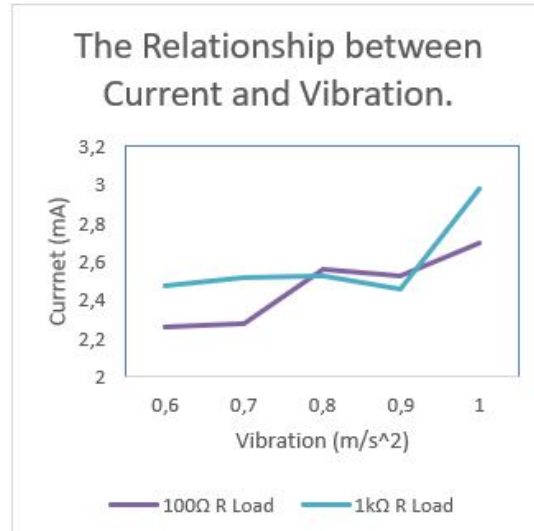


Figure 6. Graph of Current with Vibration.

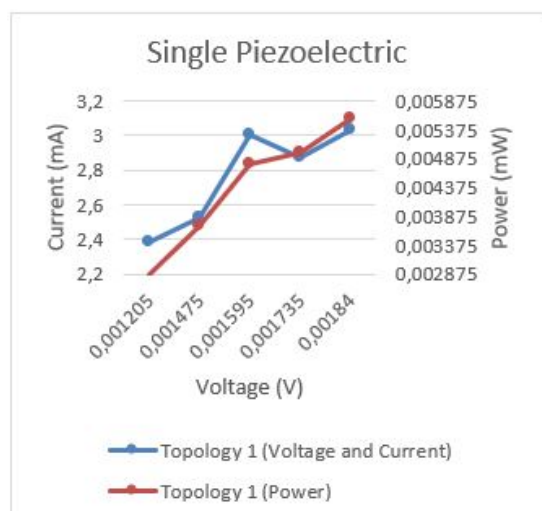


Figure 7. Output characteristic of PZT array #1.

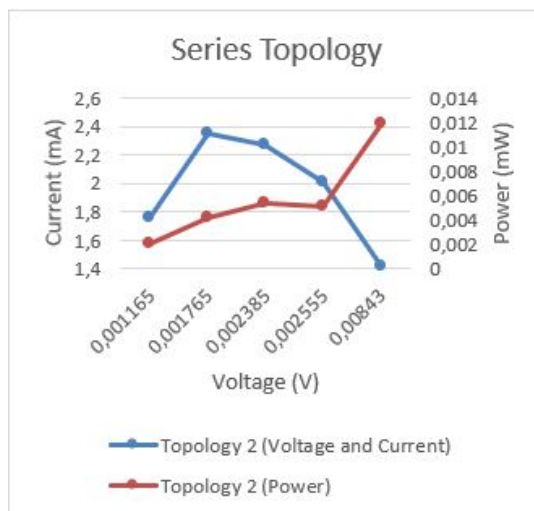


Figure 8. Output characteristic of PZT array #2.

However, direct implementation of those arrays to powering the microcontroller, sensors, and transmitter is impossible. It because the voltage dropped too much from several volts to mV. By the recent technology of dc to dc converter or PMIC, the generated voltage by PZT array could be increased and provide the necessary amount of voltage and current to the output. In addition, the supper capacitor may provide energy while there is no vibration or during harvesting.

5. Conclusion

Experimental validation of the piezoelectric energy harvester for wearable devices had tested. By using several topologies, the highest efficiency produces by topology 5. Based on microcontroller specifications, the power, which produces by topology 5 is not sufficient for giving supply to the wearable devices directly. According to the no-load characteristic of PZT array, the PEH has

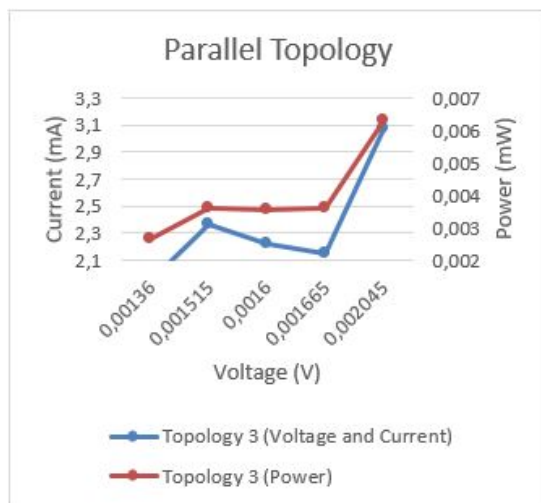


Figure 9. Output characteristic of PZT array #3.

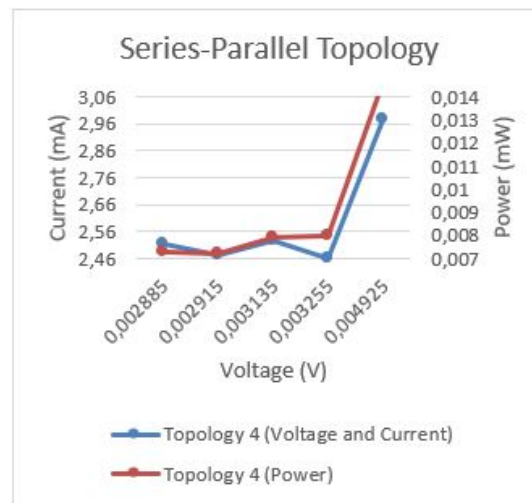


Figure 10. Output characteristic of PZT array #4.

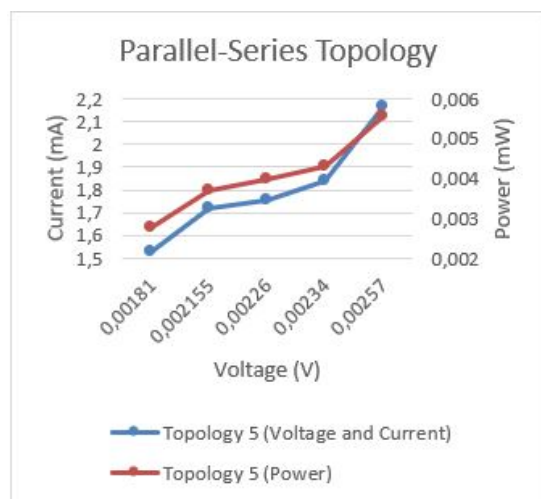


Figure 11. Output characteristic of PZT array #5.

great opportunities for replacing batteries on wearable devices. In the future, we developed the power management IC to maintaining the no-load characteristic of the PZT array.

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