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Piezoelectricity as an Alternative Source of Power Generation in Ghana

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Abstract— In this era of technology advancement, the demand for electricity for industrial and services deliver is on the constant rise. The main challenge is the exponential increase in the demand for electricity and the lower rate of electricity generation to meet this higher demand. That notwithstanding, there is a need to design and develop new energy sources to meet the current market demand. One of the sectors that have attracted much interest is the generation of energy using devices such as Piezoelectric device which can convert other types of energy into electrical energy. Piezoelectric Energy Generation is a technique used to generate low-voltage electrical energy based on the concept of green technology. This study developed a power generation system that uses piezo sensors to generate power from human footsteps. The system allows for a platform for placing footsteps. The piezo sensors were mounted below the platform to generate a voltage from footsteps. The generated voltage could be observed by using the embedded monitoring circuitry. The monitoring circuit consists of microcontrollers which allow the user to monitor the voltage. The generated energy could be stored in 24 volts DC battery for external use. The generated energy displays also display on an LCD screen. A representation of the mass of individuals stepping on the piezo sensors against the generated voltage was illustrated graphically during the testing of the project. The study was able to achieve a high-performance energy generation system which has an output that could be used in offices and homes.

Index Terms—Energy harvesting, Devices, Pressure, Piezo tile, PCB, Piezoelectric sensors, Power generation

1 Introduction

Over the years, electricity continues to be a significant determinant of the economic growth of a country. Its usage cuts across activities in residents for lighting and heating; and Industries to power machines in the industrial sector [1]. Electricity is also essential in the sectors of education, mineral exploitation, effective communication, healthcare delivery, transport and many more; serving as the basis upon which a nation's economy successfully thrives. This draws critical attention to how indispensable electricity is for human existence in the 21st century [2]. Power generation in Ghana comes with various challenges that need to be dealt with. These challenges are attracting the attention of scientists, economists, and engineers, who do not only understand the current trend of the impacts but also, plan for future challenges. Challenges plaguing the Ghanaian sector include high levels of distribution losses, lack of revenue due to the non-payment of bills and poor tariff structure, which makes it difficult for the power utility companies to make significant investments in the service they provide, to improve the sector due to financial constraints. There are opportunities; however, in the energy sector paving the way for the introduction of renewable energy sources to the stock of power generations, knowing that the country has the potential to exploit renewable energy resources. In light of this, regulatory frameworks have been laid in the country such as the Renewable Energy Act in 2011, which permits power production through the utilization of renewable energy (i.e. energy obtained from non-depleting sources) sources in an environmentally sustainable manner [1, 2].

Based on the inability of the country to provide adequate power for daily activities, The Institute of Statistical, Social and Economic Research (ISSER) in 2014 estimated Ghana to have lost between $320 million and $924 million per annum in productivity and economic growth due to power crises (Guide to Electric Power in Ghana, 2005). While Ghana has committed itself to provide universal access to electricity by 2020, the challenge is the capacity to meet this goal and, most importantly, ensure that supply is adequate and reliable. Piezoelectric materials are used as a means of transforming ambient vibrations into electrical energy that can then be stored and used to power other devices. However, the new upwelling of microscale devices, piezoelectric power generation can offer a convenient alternative to traditional power sources used to operate certain types of sensors/actuators, telemetry, and Micro-Electro-Mechanical Systems (MEMS) devices [3, 4, 5].

Much of the research into power gathering has focused on methods of accumulating the energy while allowing the intended electronics to be powered. Cited is the implementation of piezoelectric materials in harvesting energy from the movement of individuals and its use for various applications like charging the mobile phones in this case. Hence the project designs a power generation model with piezoelectricity that can be utilized to produce electricity while storing the charges in a lithium battery for later distribution to support the power demand on campuses and when researched further can be used effectively to cut down the dependence on some of the expensive power-producing plants being used to supply power to devices in the Universities and the country [5].

1.1 Literature Review

According to [5, 6, 7], electricity is an essential community that drives the economy of every nation and define the lifestyle of the people. In organizations, government institutions and the Universities uses electricity for various purposes. The most critical usage is it electronic communication infrastructure such server, transmission systems and end-to-end resources

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sharing and delivery system [8. 9]. The communication transmission systems such as fiber optics management plant [10] require a constant supply of electric power to ensure the reliability of service delivery. The demand for electricity has called for generation mechanisms to ensure maximum supply is met. Piezoelectricity generation, according to [2, 11, 12], is one of the most cost-effective forms of producing green energy. Piezo is reliable, convenient and easy to handle. The power produced by the piezo system can be stored into batteries for external use, and it can also be converted to alternate current.

2 STRUCTURE, OPERATION AND MODEL

Systems involved in this project are energy harvesting systems involving the conversion of dynamic compression of floors by people walking across piezoelectric materials to convert the pressure over the surface into electrical energy, which exhibits electromechanical coupling between the electrical and mechanical domains [11, 13]. When the piezoelectric sensors receive people walking across the piezoelectric materials, mechanical vibration energy will then generate electric power, and this electric energy is also known as piezoelectricity. The electricity will then be connected to a voltage double-circuit; having a diode as a rectifier and transformed to an alternating current (AC) and then to direct current (DC) [14, 15]. When there is a direct current voltage, this voltage will be stored in the Lithium battery charger circuit, which acts as a collector to electric energy. Next, the recommendation areas for this energy harvester circuit are at pedestrian routes, and this project has a connection to a power supply to charge a device such as a phone in this case [4, 10].

2.1 System Structures

A pressure sensor typically acts as a transducer; it generates a signal as a function of the pressure imposed. The sensing element responsible for identifying and enumerating the effects of applied pressure produces an output that cannot be used directly in an electronic circuit – like a microcontroller-based system. The physical reply needs to be translated into an electrical signal, and then signal conditioning is required to create a suitable, usable signal [15, 16]. Finally, signal conditioning may be needed, subject to the type of sensor and the application. The pressure-sensing mechanism is demonstrated in figure .1.

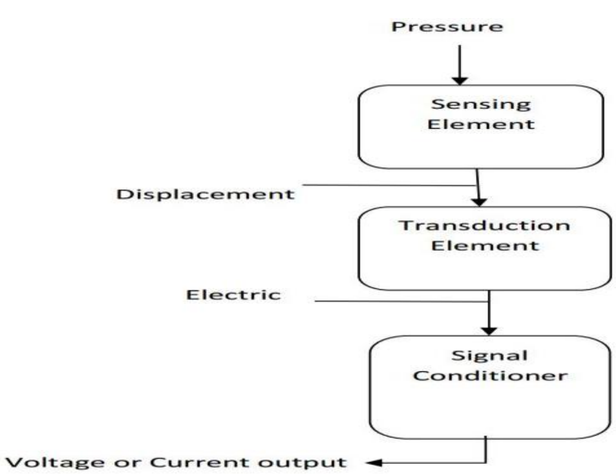


Figure. 1. Pressure Sensing Mechanism

The system architecture of a system is the structure of the system, which comprises software elements, the visible properties of those elements, and the relationships among others. It involves identifying major system components and their communications. The architecture in figure 2 consists of the power supply, PCB and electronics, the system battery, display screen and the piezoelectric tile [13].

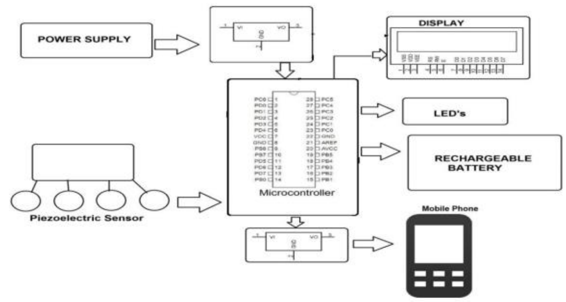


Figure. 2. System Architecture

A printed circuit board, or PCB in figure 3, is what holds the electronic components together and also gives electrical paths for their interconnection. PCB boards usually have copper bases for the electrical path known as the copper layer in figure 4. The other side is usually fibreglass, composite epoxy, or other laminated materials that give good mechanical strength to the PCB. The component can be mounted in through whole fashion as well as in surface mount. Steps in PCB design include the PCB file creation, Loading CNC files, Isolation milling, Drilling, Component mounting, Soldering [15, 16].

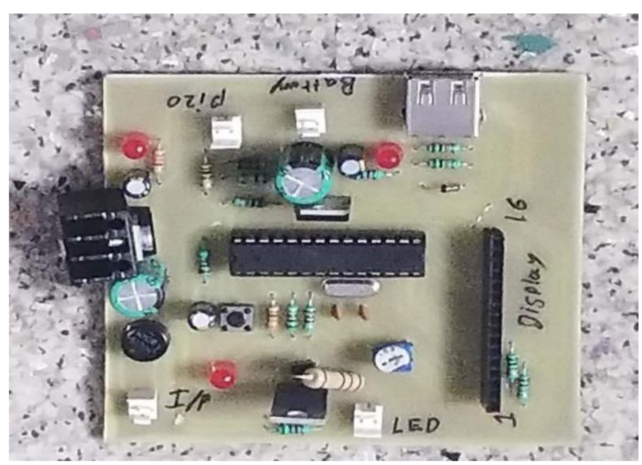
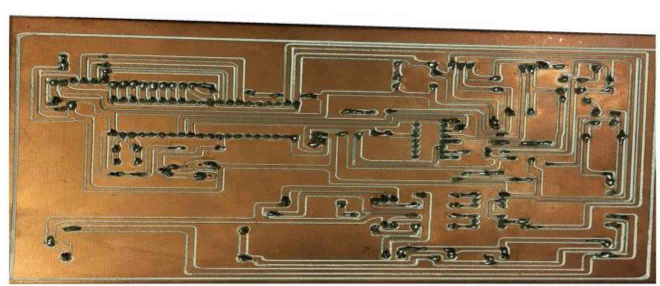


Figure. 3. PCB with Electronic Components



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The image in figure 5 is the piezoelectric tile which acts as the mat for the exertion of force to produce the necessary pressure to cause the piezo crystal to be excited to produce the voltage needed. The piezo tile is made up of a plastic plate, plastic cork, piezoelectric crystal, electrical cable and Cushion material. The plastic tile is 12cm by 14cm. The cork is 2cm in radius, and the disc is standard 1.5cm in radius [17]. The piezo crystals are strategically and analytically placed to get the maximum output voltage. In the assembling of the piezoelectric tile, the electrically conducting wire was soldered to the piezoelectric disc; the positive terminal to the interior Rochelle salt and the negative terminal to the exterior gold-plated disc. In order to get high voltage, a circular disc cork is placed on top of the piezo cell. The cork also prevents the sensor from mechanical damage when the exerted force is too excessive. The plastic plate is then placed on top of the cork to affect the distribution of pressure. The cushioning material is placed under the piezoelectric sensor to prevent scratches [12, 14, 18].

Figure. 5. Piezoelectric Tile

2.2 System Operations

The power generator is working on the principle of piezoelectric effect, which is the ability of certain materials to generate an electric charge in response to applied mechanical stress, as indicated in figure 1. The unit cells of a piezoelectric crystal are not symmetrical as is the case in most crystals. Typically, piezoelectric crystals are electrically neutral: the atoms inside them may not be symmetrically arranged, but their electrical charges are perfectly balanced: a positive charge in one place cancels out a negative charge nearby. However, if you squeeze or stretch a piezoelectric crystal, you deform the structure, pushing some of the atoms closer together or further apart. This affects the balance of positive and negative charges and causes net electrical charges to appear. The effect carries through the whole structure, so net positive and negative charges appear on the opposite, outer faces of the crystal. The charges no longer cancel one another out, and the positive and negative charges appear on opposite crystal faces. Squeezing the crystal produces a voltage across the opposing faces of the piezo crystal which is known as piezoelectricity. In our project, we have used the same phenomenon of producing piezoelectricity from piezoelectric crystals in the form of coin-shaped discs. When one steps on the piezo tile, the piezoelectric disc gets compressed and goes through the processes indicated in figure 1. After the legs are lifted, the crystal is decompressed. Thus, a full vibration is sensed by the crystal disc, and a voltage across it is produced. The voltage is sensed by the voltmeter and displayed on its LCD display. Also, at the same time, this voltage is used to charge a 12V battery. LEDs have been mounted under the piezoelectric tile that is switched on by relay through 555 timer IC whenever a voltage is generated. A glowing LED notifies this event on the PCB. Thus, whenever a person walks through the piezoelectric tile, the battery gets charged due to the voltage, which is also displayed on the LCD connected to the PCB unit of the project. The battery can get fully charged as more people throng on the tile. The battery can, in turn, be used to power some other electrical device. The cork placed on top of the piezoelectric sensor has a physical property and influence: When a force is applied to the plastic tile, it has to produce a pressure which affects each of the eight piezoelectric sensors [18].

$$\text{Stress or Pressure} = \text{Force} \;/\; \text{Area} \qquad (1)$$

$$P = F / A$$

Since the pressure applied will be equal to all piezo disc, thus,

$$P = 1 / A \qquad (2)$$

What this means is that, as the area of the applied force decreases, the more the pressure becomes, causing more stress to the piezo disc. Hence to reduce the cross-sectional area of 27cm by 22cm tile to 2cm radius cork stresses a piezo disc of 1.5cm radius the more.

3 EXPERIMENTATION AND DISCUSSION

An analytical overview of the system developed, and an indebt analysis of the working of the system alongside the hardware and power testing of the system is discussed here. In the later sub-chapters, correlated analysis of the mass of the body that exerts the force and the power generated and the need for a storage means are also put in this issue.

3.1 Hardware Testing

The success of this project depends highly on the success of the various components used in this project. Before the whole system is put to use and analyzed, the unit hardware components have to be tested to see if their desired properties meet the reason for their creation. Hence, a continuity test is performed by placing a small voltage (wired in series with an LED or noise-producing parts such as a piezoelectric speaker) across the chosen path. If electron flow is inhibited by broken conductors, damaged parts, or excessive resistance, the circuit is "open". Devices used to perform continuity tests was multimeters which measured current and specialized continuity testers which are cheaper, more basic devices, generally with a simple light bulb that lights up when current flows. An important application was the continuity test of a bundle of wires to find the two ends belonging to a particular one of these wires; there will be a negligible resistance between the "right" ends, and only between the "right" ends. This test was

TABLE 1
MASS TO VOLTAGE TO CURRENT RECORDINGS

mass (kg)	40	45	50	55	60	65	70	75
voltage (V)	5.36	8.50	6.50	9.10	12.75	16.60	15.75	20.20
current (mA)	2.3	6.0	4.5	8.0	9.1	11.4	10.2	12.1

performed just after the hardware soldering and configuration has been completed. This test aims at finding any electrical open paths in the circuit after the soldering. Many times, the electrical continuity in the circuit is lost due to improper soldering, wrong and rough handling of the PCB, improper usage of the soldering iron, component failures and presence of bugs in the circuit diagram. We use a multimeter to perform this test. We kept the multimeter in buzzer mode and connected the ground terminal of the multimeter to the ground. We connected both the terminals across the path that needs to be checked. Once there was a continuation, then beep sound would be heard.

Furthermore, the power-on test was performed to check whether the voltage at different terminals is according to the requirement or not. We take a multimeter and put it in voltage mode. This test was typically performed without a microcontroller. Firstly, we checked the output of the transformer, whether the required 12 voltage was recorded. Then we applied this voltage to the power supply circuit. We did this test without a microcontroller because if there was any form of excessive voltage, it might lead to damaging the controller. We checked for the input to the voltage regulator, i.e., are we getting an input of 12v and an output of 5v. This 5v output is given to the microcontrollers' 40th pin. Hence, we check for the voltage level at the 40th pin. Similarly, we check for the other terminals for the required voltage. In this way, we can assure that the voltage at all the terminals is as per the requirement.

3.2 Mass to Power Correlation

This phase of paper is focused on the correspondence between the mass of the impacting body and the power generated. In the interim, why some implementation path was taken. When a person steps on the piezoelectric board, the stacks under the piezo tiles ensure that pressure applied was concentrated on the piezo disc for the maximum output voltage. People of varied weight from 40kg to 70kg were made to walk on the piezo tile. The mass for the bodies of those who stood on the piezoelectric disc was taken for the purpose of this analysis. The observations made are illustrated in Table 1.

TABLE 2
MASSES AND THEIR CORRESPONDING POWER

mass (kg)	40	45	50	55	60	65	70	75
power (mW)	12.33	51.00	29.25	72.8	116.03	189.24	160.65	244.40

From the graph representation in figure 6, it can be inferred that there is a linear correlation between mass and voltage by the piezoelectric tile. Exceptions on the 45 to 50 masses and 65 to the 70 masses are due to the intensity of the force; i.e. the person jumped to increase the force. This draws attention to the fact of velocity as an influence on the voltage produced. Statistically, the average voltage produced from nine steps is 10.53V. Taking this average, theoretically, a total voltage of 10.53V will be produced from a hundred steps.

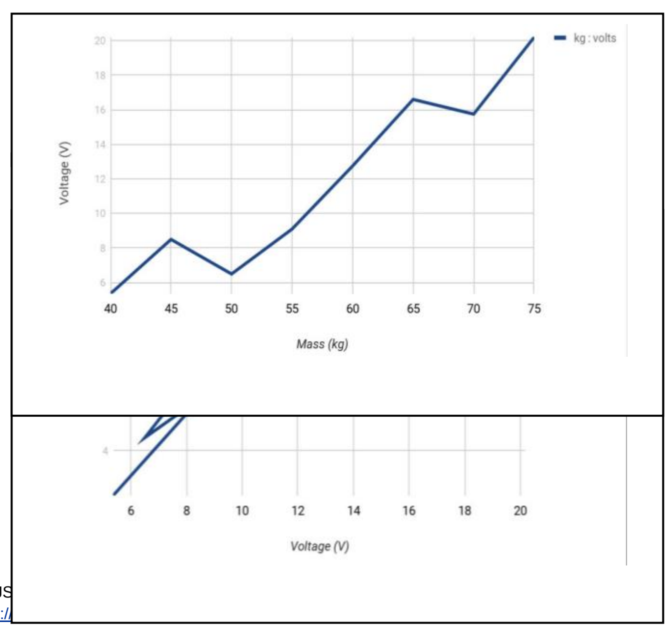

Figure. 7. Graph of Voltage against Current

From figure 7 of a volt to current, the graph shows the two quantities are linear.
These proportions can summarize these two graphs:

$$V \propto m \quad (3)$$

and

$$V \propto I \quad (4)$$

thus

$$I \propto m \quad (5)$$

The equation gives electrical power;

Power, P = Current (I) x Voltage (V).

$$P = VI \quad (6)$$

The illustration in Table 2 concludes that;

$$P \propto m \quad (7)$$

Maximum weight produced a power of 244.40 mW.
This power is too small to keep devices running hence the need to store in batteries.

4 Conclusion and Recommendation

The project which makes use of wasted energy of foot power with human locomotion is proven to be very much relevant and important for use in the highly populated towns, cities and centres e.g. educational institutions (the University of Energy and Natural Resources). The whole human/bio-energy being wasted if made possible for utilization will be great for crowded energy farms and will be a very useful alternative source of power generation. The project is proven to be an economical, affordable, and environmentally-friendly electric energy solution which can be used mainly by the University to support the power demands on campus and the country Ghana.

This energy generation system can be enhanced in the future by being integrated into our road networks to help generate power from moving vehicles. Software integration into the system in the future is also feasible to provide real-time information about the state of the system, the amount of energy produced, predict the devices that can use the generated power, time for the power generated to elapse, etc. to the end-user. This non-conventional energy system is essential at this time to universities and our country; hence we recommend further research and implementation of our model to support power generation systems in the country.

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