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Prototyping and Performance Analysis of a Step Driven Piezoelectric Energy Generation System

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Abstract
This paper presents a novel approach to harness energy from human footsteps using piezoelectric sensors. With a focus on addressing the energy needs of densely populated regions such as China and India, where foot traffic is abundant, this work endeavours to convert mechanical energy from footsteps into electrical energy. A prototype hardware model has been designed and presented to generate power through human foot movement, employing piezoelectric sensors arranged in series and connected via a rectifier diode to charge a battery. Additionally, a voltage booster is integrated to amplify voltage output, while an inverter facilitates the conversion of DC to AC power. Experimental investigations were conducted by varying the weights of individuals to establish a correlation between weight and resulting voltage outputs, culminating in a graphical representation of the data. The outcomes of our study showcase the feasibility of tapping into untapped energy reservoirs from foot traffic, thereby presenting promising applications for urban settings. This work contributes towards addressing energy challenges prevalent in densely populated areas and underscores the potential of piezoelectric energy harvesting technology as a sustainable energy solution.
Keywords: *Batteries, Inverter, Piezoelectric sensors, Rectifier diode and Voltage booster.*

1. Introduction
Currently, electricity plays a crucial role in human daily activities, and the demand for electricity is rapidly increasing. Modern technology relies heavily on electricity for various operations, leading to electricity generation being a major contributor to pollution worldwide. The escalating demand for electricity has created a significant gap between supply and demand. In response, researchers and pioneers in the energy harvesting industry are exploring alternative sources of energy to provide a pollution free method of electricity generation that does not harm the environment. The primary goal is to invent a sustainable technology that can meet the growing energy needs of human population. One important aspect of technology is the piezoelectric effect, which occurs when materials that exhibit it undergo pressure and strain and produce an electrical charge. Moving people can apply pressure, which piezoelectric sensors can transduce into electric current. The piezoelectric sensor-based power generation design activated by pressure from footsteps is presented in this paper. An in-depth analysis of the advantages, disadvantages, sub-equipment, and requirements of this technology is provided. The utilization of piezoelectric materials for energy harvesting has garnered considerable attention in recent years due to their ability to convert mechanical strain into electrical energy efficiently. Several studies have explored various applications of piezoelectric energy generation, particularly focusing on harvesting energy from ambient vibrations and mechanical movements. Wang et al. (2018) investigated the feasibility of using piezoelectric nanogenerators to capture energy from human motion, highlighting the potential of such technology in wearable electronics. Similarly, Yang et al. (2020) explored the integration of piezoelectric

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sensors in floor tiles to harvest energy from foot traffic in indoor environments. These studies demonstrated the practicality of piezoelectric energy harvesting in different contexts, laying the groundwork for further advancements in this field. In the realm of urban energy harvesting, Li et al. (2019) developed a piezoelectric energy harvesting system embedded in pavements to capture energy from vehicular traffic, showcasing the scalability and adaptability of piezoelectric technology in urban settings. Furthermore, Kim et al. (2021) proposed a hybrid energy harvesting system combining piezoelectric and solar technologies to enhance energy generation and sustainability in urban infrastructure. Despite these advancements, challenges such as optimizing energy conversion efficiency, ensuring durability of piezoelectric materials, and integrating harvested energy into existing power systems remain areas of active research. The work conducted by Zhang et al. (2022) addressed these challenges by implementing a robust

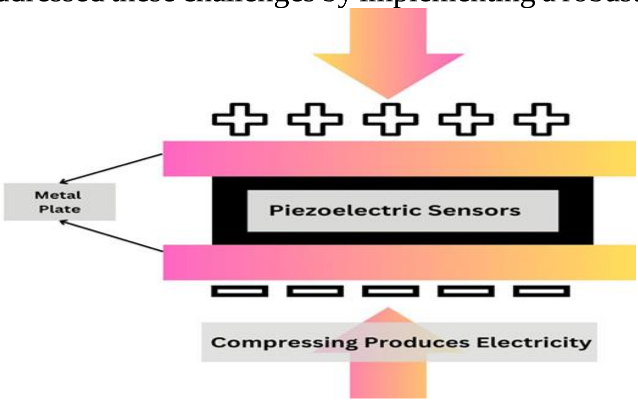

Figure 1 Piezo Electric Working

piezoelectric energy harvesting system capable of withstanding varying environmental conditions and efficiently converting mechanical energy into usable electrical power. Building upon the state-of-the-art research, the present study focuses on developing a practical solution for harnessing energy from human footsteps in densely populated areas. By integrating piezoelectric sensors into a prototype hardware model and conducting experimental analyses, this research aims to contribute to the ongoing efforts in sustainable energy harvesting technologies. Many research organizations are working hard to develop piezoelectric methods for footstep sensors based on footsteps. The ever-increasing energy demands for human well-being have led to power generation. Arvind et al. suggested using human movement to generate power, while Yaramasu et al. used the same technology to introduce a high-power wind energy conversion system [1-4]. A wireless transmitter that runs independently and is controlled by a foot pump urine source was proposed by Taghavi, Andrew Stinchcombe, et al. Figure 1 shows Piezo Electric Working.

2. Working Principle of Proposed Energy Harvesting Unit

Ferroelectric materials include piezoelectric ceramics such as $PbTiO_3$, $PbZrO_3$, PVDF and PZT, where the piezoelectric effect is prevalent. At the core of the current beneath the piezoelectric sensor is the footstep power generator, functioning as demonstrated. The efficiency of the current footstep power module heavily relies on the choice of piezoelectric material, making the selection process crucial. PZT stand out as the most readily available piezoelectric materials, prompting to determine the most suitable option. The primary criterion for selection was the attainment of higher out voltage under various applied pressures. The piezo electric sensors produce AC voltage, subsequently converted to a DC power supply through rectifier diode. The resulting DC outputs are stored in three batteries, each with a four-volt capacity. By connecting these batteries to an inverter, the 12V that is stored can be converted to 220V AC. Afterwards, different loads are operated using the generated AC output power. It makes sense when we look at the block diagram shown in Figure 2.

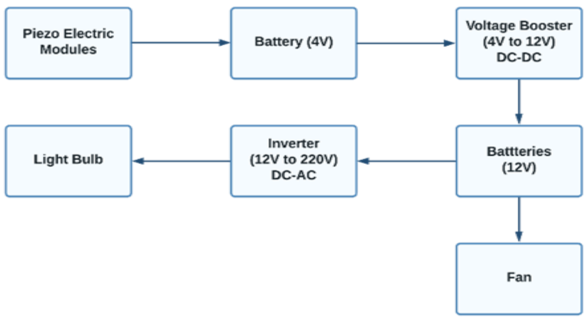

Figure 2 Block Diagram for the System that Generating Energy

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2.1. Working Principle

The substantial number of electric dipoles present in piezoelectric materials is intimately related to their nature. Since a dipole is a vector, its direction and value vary depending on the nearby electrical charges. Collectively referred to as Weiss domains, these dipoles have a tendency to point in the same direction. When mechanical stress is applied, the crystalline structure is disrupted, which alters the direction of the polarization of the electric dipoles and is the reason why piezoelectric materials produce a voltage. Reorienting molecular groups or rearranging ions within the crystalline structure could be the cause of this change. Consequently, greater mechanical stress leads to a greater polarization change and increased electrical output. This sensor functions on the basis of a physical quantity that is converted into a force and acts on the two opposing faces of the sensor element. There are various applications for the pressure variations. Piezoelectric microphones and piezoelectric pickups for electrically amplified guitars are examples of the most widely used form of sound.[5-9].

2.2. Piezoelectric materials and its effects

The term "piezoelectric effect" or "piezoelectricity" refers to a material's capacity to produce an AC voltage in response to vibration or mechanical stress. Figure 3 shows Overview of Energy Harness Through Footstep. Materials that demonstrate this effect include:

- Berlinite (AlPO4),
- Quartz (SiO2),

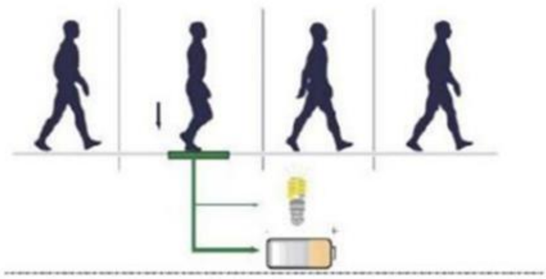

Figure 3 Overview of Energy Harness Through Footstep

- Tourmaline Barium Titanate (BaTiO3)
- Gallium orthophosphate (GaPO4), various other solids.

Both direct and reverse effects of piezoelectricity are possible; that is, mechanical stress leads to the production of AC voltage and vice versa. Figure 4 shows Direct Depiction of Piezo Electric Sensor. The term "piezoelectric effect" refers to a material's capacity to produce an electrical charge in response to mechanical stress. Examples of such materials include quartz, topaz, zinc oxide, and others. The Greek word "piezein," which implies to press, squeeze, and push, is where the word "piezoelectric" originates.[8-11].

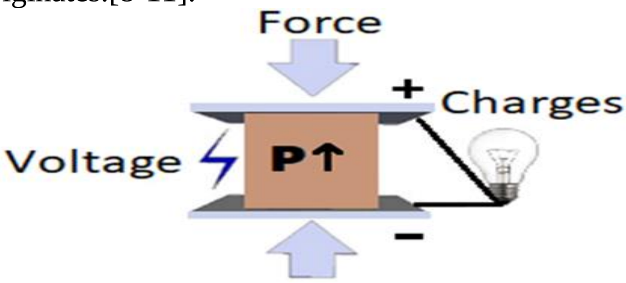

Figure 4 Direct Depiction of Piezo Electric Sensor

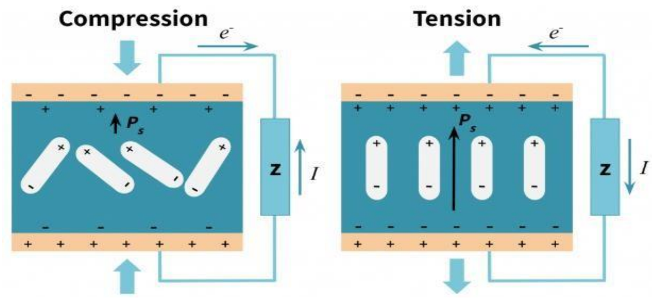

Figure 5 Basic Contractions

Furthermore, when mechanical stress is applied to the piezoelectric material, the piezoelectric effect is reversible. On output, we get a small electrical charge. Additionally, the Figure 6 piezoelectric material compresses or stretches when electricity is applied to it.

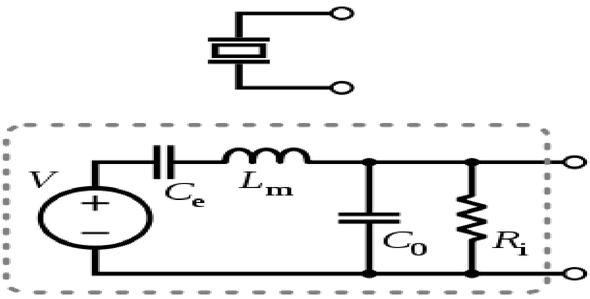

Figure 6 Equivalent Circuit of Piezoelectric

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The application of the piezoelectric effect sensor includes:

- Sound generation and detection
- Production of high voltage
- Generation of Electronic Frequencies
- Small-scale equilibrium
- Ultra-fine optical assembly focusing
- Commonplace devices like lighters

3. Component Description

3.1. Piezo Electric Sensors

Piezoelectric sensors are instruments that transform changes in force, strain, temperature, acceleration, or pressure into electrical charges by the application of the piezoelectric effect. An electric charge is produced across a crystal's faces when a force is applied to a piezoelectric material. As seen in the illustration on the right, this can be measured as a voltage that is proportionate to the pressure. Physical factors like pressure, tension, or acceleration are converted into an electrical charge via a piezoelectric sensor so that it may be detected. They work effectively with common objects because of their modest size and extreme sensitivity. The pressure sensor transfers the force via a thin membrane applied to the piezoelectric element that is positioned atop a substantial foundation. the piezoelectric material to become loaded and begin producing electrical voltages. The voltage generated is directly proportional to the applied pressure. Compared to other metals, it has an extremely high modulus of elasticity that can reach up to 10e6 N/m2. The mechanical tension is transformed into electrical voltage by it. A wire can be used to remove the electrical charge that builds up on the crystal when mechanical tension is applied to the sensor. A piezoelectric material experiences polarization P, a linear function of T, when it is subjected to stress T: P=dT (d: piezoelectric strain constant). D=εE represents the relationship for a dielectric material, between electrical displacement D and electric field strength E.

Basic equation for the piezoelectric effect:

Dn = (m, n=1,2,3; I, j=1, 2, ... 6) = dnjTj + εTnm Em

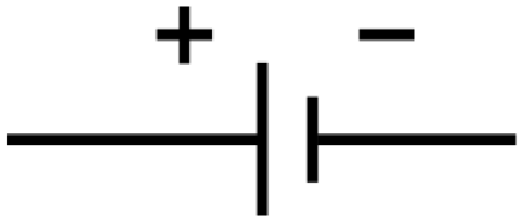

Figure 7 **Piezo Sensor Array**

As seen in Figure 7, we can imagine an RC Network and an alternating current source as two examples of piezoelectric sensors. Each piezoelectric sensor has a double tape applied to it for enforcement and protection. On this tile 10 piezoelectric sensors are installed. Since one piezo sensor can only produce a very small amount of power, several piezo sensors are combined. There are two possible configurations for installing the piezo sensors:

- Connection in Series
- Connection in Parallel

There is an increase in voltage output when the sensors are connected in series, but the voltage is not linear. However, when a parallel combination was used, the voltage output did not increase to a satisfactory degree. If a combination of series and parallel connections is used to generate a high current density voltage output.

3.2. Batteries

Firstly, we have taken a single cell of 4 volts for the input from the Piezo electric Modules, after boosting through the booster module we have arranged three cells to store the boosted voltage that is around 12 volts.

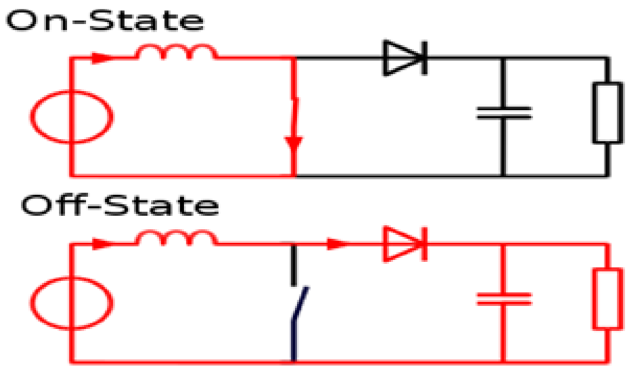

Figure 8 **ON and OFF State of Converter**

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One or more electrochemical cells capable of powering electrical devices through external connections make up an electric battery, which is a source of electric power. When a battery is in its anode the negative terminal it is in its cathode, or positive terminal is generating electricity. Electrons that are directed toward the positive terminal via an external electric circuit originate at the terminal designated as negative. Figure 8 shows the ON and OFF State of Converter.

3.3. Voltage Booster Module

A DC-to-DC converter that reduces current from its input (supply) to its output (load) while increasing voltage is called a boost converter or step-up convert Boost Converter on and off states. An inductor's propensity to withstand variations in current by altering the amount of energy retained in the inductor magnetic field is the fundamental idea behind the boost converter. A boost converter's output voltage is always higher than its input voltage.

A boost converter works on the basis of two different states:

- When the switch is in the on position, it closes, which causes the inductor current to rise.
- When the switch is in the off-state, The only paths that the inductor current can take are via the flyback diode D, the capacitor C, and the load R. As a result, the energy that has accumulated while the device is in the on state is moved into the capacitor.

As can be observed, the input current equals the inductor current. As a result, it is not abrupt like a buck converter, and there are less restrictions on the input filter than there would be with one.

3.4. Inverter or DC to AC Converter

An inverter is an electrical device or circuit that changes direct current (DC) to alternating current (AC). The specific device being used determines the final AC frequency. Reversers, which were formerly substantial electromechanical devices that converted AC to DC, perform the opposite function as inverters. A steady DC power source with sufficient current to meet the system's intended power requirements is necessary for a standard power inverter circuit or device. Figure 9 shows the DC to AC Converter. The inverter's design and intended use determine the input voltage. Generally, we have:

- A steady DC power source with sufficient current to meet the system's intended power requirements is necessary for a standard power inverter circuit or device. The inverter's design and intended use determine the input voltage.
- The common standards for home energy systems are 24, 36, and 48 V DC.
- When photovoltaic solar panels are used for power, the voltage drop is between 200 and 400 V DC.
- The voltage drops in vehicle-to-grid systems utilizing electric vehicle battery packs ranges from 300 V to 450 V DC.
- Hundreds of thousands of volts when the inverter is a part of a high-voltage direct current power transmission system.

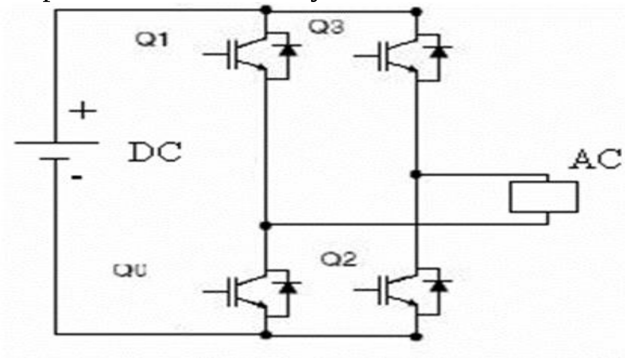

Figure 9 DC to AC Converter

4. Theoretical Analysis

Charging Time = Rating of Battery / Charging Current

Theoretical Power Output:

- It's critical to obtain the force applied to the model in order to calculate the output power. Figure 10 shows the Hardware Setup. Therefore, the force should be computed as
- Force = Weight applied by the human body (here)
- Power = Voltage * Current
- We can get different Powers practically by taking readings of the Voltage and Current for different force applied on the piezo electric sensor.
- The experimental hardware configuration of

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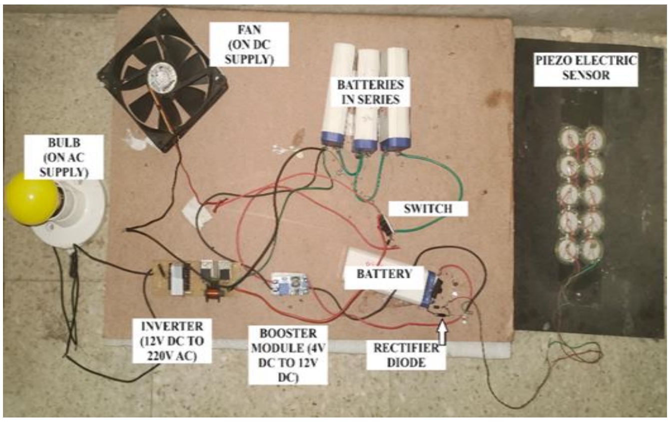

Figure 10 Hardware Setup

5. Result and Discussion

Figure 11 shows the footstep power generation system 4. It is made up of piezoelectric modules, diodes, capacitors, and an inverter that converts 12V DC to 220V AC. We intend to utilize ten piezoelectric modules in total. At this point, the rectifier diode is charging a condenser. After that, the 4V battery is being charged, and the booster module is connected. We will use a rectifier diode, such as the 1N4007, to arrange for the transformation of the AC power into DC due to the modules that will produce the AC voltage are piezoelectric. The rectifier diode is currently charging a condenser. The booster module is then connected, and the 4V battery is being charged. At this point, the rectifier diode is charging a condenser. After that, the 4V battery is being charged, and the booster module is connected. The characteristics of V-F, or voltage-force. To understand the relationship between the output and the various forces acting on the piezoelectric materials under consideration, characteristics (as shown in Figure 5) were examined. The voltages developed across the setup of the piezoelectric modules are measured using a multimeter. Different voltage outputs were obtained in accordance with the various forces applied, as different observed forces (weights) were confirmed on the piezoelectric module setup. By charging the capacitor and then discharging it as necessary, energy can be stored in this manner. It's not immediately clear, though, how this cycle might be used to capture energy. DC to DC booster module can be used in place of the bridge rectifier step in order to solve this issue.

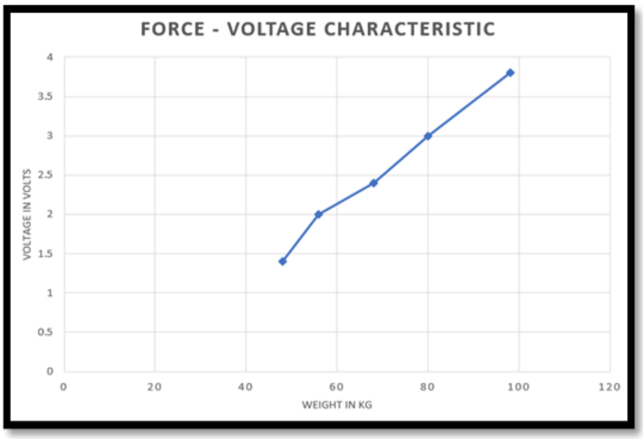

Figure 11 V-F Output Graph

Table 1 F-V Characteristics

Force (wt. in kg)	Voltage (in volts)
48	1.4
56	2.0
68	2.4
80	3.0
98	3.8

The Table 1 is calculates the F-V Characteristics DC voltage will be kept in 4V cell, then through booster module it is being boosted from 4V to 12V (DC-DC) and then it is charging the three 4V batteries connected in series making it work as a 12V battery. Then the output from the batteries connected in series is taken to the inverter. The inverter is a 12V DC to 220V AC inverter. To check the obtained result, we have connected a bulb. To check the DC output of the battery connected in series it is connected to a fan.

6. Advantages

- No negative effects on the human body.
- Easily utilized in places where people move around a lot, such as malls and roads.
- Simple to set up.
- The number of steps determines how much

energy is produced.

- Easy to use and intuitive utility.

Conclusions

We have computed the several approaches for piezoelectric sensor-based foot step creation in this study. All of the supporting equipment for the experimental setup is covered. The output voltages have been discussed in relation to the results. The force vs voltage diagram illustrates the voltage generated at various supplied weights. The benefits include the ability to generate power only by walking on the step without the need for fuel, the ability to generate power while exercising or jogging on the step, and the ability to store conventional power in a battery. As it is only applicable in that specific location and only a certain amount of power can be produced using the traditional integrated circuits (ICs) now on the market, future research endeavors may aim to address these limiting issues. In the future, we will apply the similar concept to commercially used treadmills, staircases, and other areas where people frequently congregate. In addition to footstep charging technologies, we may also offer solar charging options to speed up charging. These would be helpful in instances where there is less movement on the piezo electric sensors, such as on holidays or during curfews.

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