Piezoelectric-Based Footstep Energy Generation and Storage System

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Abstract- As demand grows for renewable and sustainable sources of energy, there continues to be growing interest in energy harvesting technologies. One specific area being explored is generating electricity by using one's movement, specifically, using our feet. This paper will provide a description of the development of an energy generation and storage device using a piezoelectric based footstep energy generator.

This energy harvesting system consists of a piezoelectric array sensor placed under a surface area such as a platform. When the user of the platform inhibits a foot instinct on the surface area of the platform, the mechanical pressure exerted on the sensors creates electrical voltage due to the piezoelectric effect. The generated voltage is in the form of alternating current. Hence an AC/DC rectifier circuit is used to convert the alternating current to direct current. The DC voltage output is further conditioned through the use of a filter capacitor and stored in an energy storage device like a capacitor or supercapacitor.

Voltage regulators help ensure that stored energy can be utilized effectively to power electrical devices, including LEDs and monitoring equipment. The proposed device is able to function as a conversion device for converting energy from foot traffic into usable electrical energy. Possible use of this type of technology would be in high-density traffic locations such as railway stations, airports, shopping malls, and sidewalks for generating small amounts of renewable energy.

Keywords: Footstep Energy Harvesting, Piezoelectric Sensors, Renewable Energy, Energy Storage, Rectifier Circuit, Low-Power Systems.

I. INTRODUCTION

As demand for energy increases globally with population growth and urbanization, traditional energy sources like fossil fuels cannot meet this increase in demand over time. We are therefore into the area of study of alternative energy resources.

Energy harvesting refers to the process of collecting and storing small (about milliwatt) amounts of energy from our external environment. One form of energy harvesting that can be utilized fairly well is mechanical energy generated through movement by people.

Roughly one of most widely used methods for converting mechanical energy to electrical energy involves the use of piezo-electric materials, such as quartz and specialized ceramics known as "piezoelectric" ceramics (these materials produce an electrical charge when mechanical stress is applied).

Using the above method, when a footstep hits the surface of a floor that has been installed with piezoelectric sensors, the impact/presence of the foot provides the necessary amount of mechanical stress placed upon the piezoelectric sensor to produce a voltage that can be captured and stored.

Energy harvesting systems that utilize footstep energy are an interesting way to collect renewable energy and can harvest energy in a multitude of high-foot traffic areas. The energy that is collected can supply power for small electronic devices, such as: lighting (LEDs), sensor systems, and Internet-of-Things (IoT) monitoring peripherals.

The design of a simple prototype of a device using piezoelectric sensors to generate and store electrical energy from the pressure of individuals placing their feet on a footstep platform is the objective of this project.

II. LITERATURE SURVEY

There has been considerable interest in piezoelectric energy harvesting as a way of converting mechanical energy into electrical energy generated via foot traffic. Based on research from Selim and others, one example is the development of piezoelectric floor tiles that can produce electrical energy from the impact of footfalls for low power applications such as LEDs or sensors [1]. Another example is the research conducted where Selim and others analyzed how many piezoelectric sensors in the floor would increase voltage and energy output to produce more electrical energy [2]. Kamboj and others have designed a footstep power generation device using piezoelectric sensors and rectifier circuits that illustrate the ability to convert walking into electrical energy.[3] Researchers including Hossain have developed piezoelectric floors with a force amplification feature that amplifies the pressure placed on the sensor, thus increasing the overall efficiency of the energy generated by the sensors [4]. Several other researchers have researched various configurations and sensor placement for systems capable of generating energy when a person steps on them. A concrete example is the footstep energy-generating device demonstrated by Somashekhar and others that can be used as an energy source to power low-power electronic devices such as cell phones and other small devices [5]. Shwetha et al. showed that connecting piezoelectric sensors in array configurations improves output voltage and current [6]. Rao et al. investigated the use of piezoelectric sensors in crowded public areas for sustainable energy harvesting [7]. Other studies focused on improving energy harvesting circuits and applications. Atik-Uz-Zaman et al. proposed a piezoelectric-based intelligent power management system for lighting applications [8]. Zhao and his co-authors explored the technology of piezoelectric shoes that harvest energy as humans walk [9]. Haroon and Ahmed built a system that harvests energy from the ground as we walk using PZT sensors; they demonstrated that there is an electrical output that can be measured [10]. Some researchers have examined ways to optimize electrical circuits and extract energy from PZT devices to improve the efficiency of harvesting energy [11–13]. Research on vibration-based piezoelectric systems has also shown that mechanical vibrations from human activities can be converted into useful electrical energy [14]. Furthermore, tile-based piezoelectric energy harvesting systems have demonstrated the ability to increase voltage output by integrating multiple sensors [15]. These studies confirm that piezoelectric energy harvesting is a promising technique for generating renewable energy from human motion, particularly in crowded public environments

III. METHODOLOGY

This project's methodology converts human footstep pressure into electrical energy with piezoelectric sensors. As in Figure 1 it all starts at the footstep platform that generates electricity from footsteps, containing multiple piezoelectric discs arranged in an array configuration. When someone puts their foot on the platform, they generate pressure on the piezoelectric sensors, causing the sensors to "bend" mechanically. Mechanical "bending" stress on the piezoelectric sensors produces an electrical voltage between them due to "piezoelectric effect". The voltage output of the piezoelectric sensor is alternating (AC) voltage, making it unsuitable for use by electronic devices.

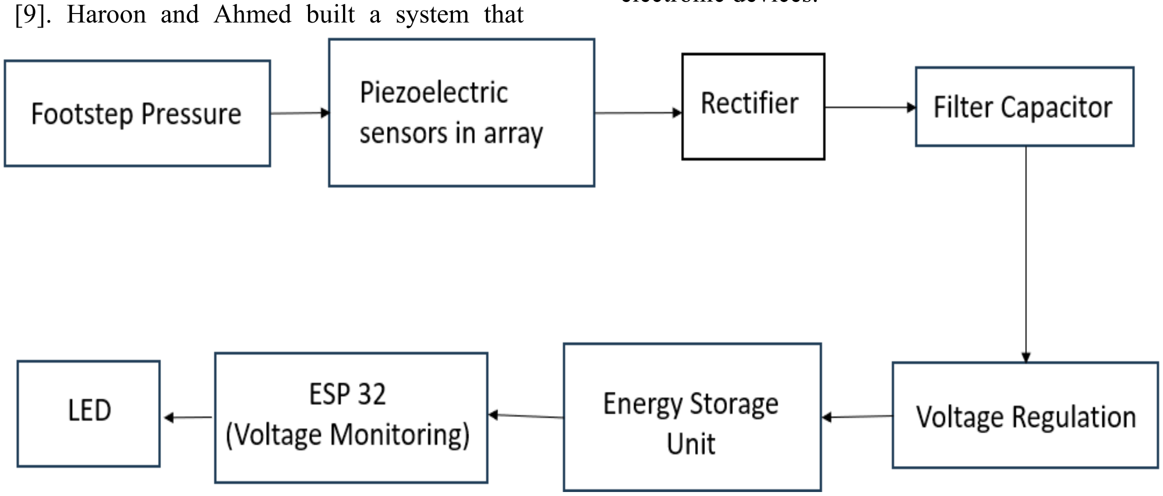

Figure 1: Flow Diagram

To convert AC voltage to usable direct current (DC) voltage, the voltage created by each footstep goes through a rectifier circuit made of semiconductor diodes. After AC signal from piezoelectric sensors is rectified, the voltage will still have ripple (fluctuations). To remove the ripple from rectified DC voltage, a filter capacitor will be added to the circuit to smooth out fluctuations in the DC signal. Energy produced from footstep activity is stored in an energy storage device such as a battery or supercapacitor. When AC voltage is converted to a usable form and the voltage is smooth, the electricity is available to be delivered to appliances by a regulated voltage.

IV. SYSTEM IMPLEMENTATION

The system implementation explains how the hardware of the entire system works with respect to converting footstep pressure into usable electrical energy. The system consists of an array of piezoelectric sensors, a rectifying circuit, an energy storage method, and a monitoring method.

4.1 Piezoelectric Sensor Array:

The piezoelectric sensor array is one of the major components making up this system. The sensors consist of multiple piezoelectric discs that are placed under the footstep platform. When someone steps down onto the footstep platform, mechanical force will act on the sensors and convert the force applied by the individual's foot to an electrical voltage as a result of the piezoelectric effect created by the piezoelectric sensors. Each piezoelectric sensor generates a small amount of voltage at its output, so multiple piezoelectric sensors will be connected together to provide more total electrical power output.

4.2 Rectifier and Filter Circuit:

The electrical output produced by the piezoelectric sensors is AC (alternating). In order to convert the AC voltage produced into usable DC voltage, a circuit called a rectifier circuit must be used to convert the voltage produced from the piezoelectric sensors to usable direct current (DC) voltage. In order to accomplish this conversion, the rectifier circuit consists of a series of 1N4007 Diode diodes connected together in a bridge configuration. After conversion from AC to DC, the output voltage of the rectifier circuit will need to be filtered through a filter capacitor to smooth out any fluctuations within the voltage output and to keep the voltage output as close as possible to the required DC voltage.

4.3 Energy Storage Unit

The rectified voltage generated by the energy harvesting circuit will be stored in an appropriate energy storage device, such as a supercapacitor. The energy harvested from repeated footfalls will be stored in the energy storage unit to be used at a later time. The use of supercapacitors as energy storage devices has advantages over conventional batteries, including the ability to charge and discharge much more rapidly than batteries and their longer lifespan.

4.4 Voltage Regulation and Boosting

The voltage produced by piezoelectric sensors usually has low levels and is unstable; therefore, a voltage regulation circuit is needed. The MT3608 DC-DC Boost Converter Module will be used to convert the low voltage from the piezoelectric sensors to a stable voltage level to power electronic loads. The MT3608 DC-DC Boost Converter Module will regulate the output voltage to a stable voltage level in the presence of input voltage changes.

4.5 Output and Monitoring System

The regulated voltage from the energy harvesting circuit will be available as output to an electronic load such as LEDs to exhibit the capability of the energy harvesting circuit. In a more sophisticated realization of this design, an ESP32 microcontroller could be used to monitor the transient voltage produced by the piezoelectric sensors while displaying the amount of energy being produced. This will allow for an assessment of the energy harvesting system.

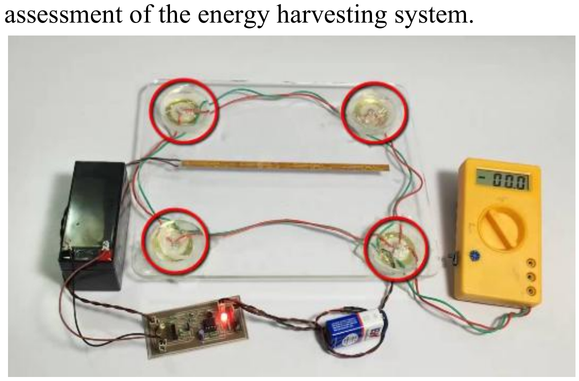

Figure 2: Experimental Setup

The installation of the footstep energy generation system can be found on the experimental setup illustrated in Figure 2. In this application, numerous piezoelectric sensors are situated on a mount that will create electrical energy through mechanical stress using the Piezoelectric Principle of operation as illustrated in the experimental setup illustration (Figure 2).

V.RESULTS AND PERFORMANCE EVALUATION

The successful demonstration of generating electrical energy from the steps of humans through the development of the prototype has exceeded expectation through research. The application of force to each of the piezoelectric discs generates a voltage to be amplified through the electrical circuits that have been designed for the prototype. The amplification and management of the generated voltage occur with a rectifier, filter, and energy storage system.

The test output from the footstep energy demonstrated several variables affecting the output produced number of piezoelectric sensors that are present on each tile, the force being put upon each tile by the foot, the frequency of footfalls on each tile, the configuration of how the piezoelectric sensors are connected to the circuitry.

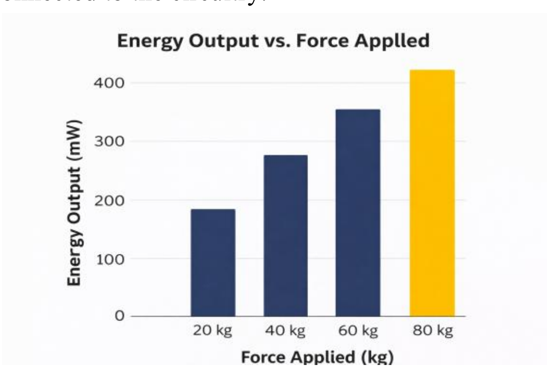

Figure 3: Energy Output vs. Force Applied

Figure 3 demonstrates how the electric power produced from piezoelectric sensors increases as the pressure applied to the piezoelectric sensor increases. This increase in electric power is a result of the piezoelectric effect.

With some of the previously reported research on piezoelectric floor tile systems, it's shown that the power output of these systems was in the milliwatt range to several hundreds of milliwatts depending on the design of the tile.

The prototype has demonstrated that harvested energy from footfalls can be used for low power applications such as powering LED lighting, sensors, and monitoring devices.

VI. CONCLUSION

This project shows a piezoelectric footfall energy capture and store device that transforms mechanical energy from people walking into electricity.

Piezoelectric sensors are used to produce electricity when mechanical load is applied. This generates DC voltage through the rectifier, filtered and stored in an energy source. The energy source provides enough energy to power small electronics such as LED lights. Although there is a limited amount of energy produced, there are many opportunities to use this technology in high-density public spaces. The design of the piezoelectric power-generation systems will continue to advance, contributing to energy resources that are sustainable and renewable.

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