Toward Sustainable Smart Cities: Design and Development of Piezoelectric-Based Footstep Power Generation System

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Abstract Smart cities involve information and communication technology (ICT) as the main features. The Internet of Things and 5G will aid smart sensing gadgets by allowing them to connect quickly and securely. Nevertheless, a significant problem in this industry will always be the requirement for active sensing devices that are self-powered and sustainable sources. Piezoelectric energy-harvesting systems are intriguing prospects for creating smart and active self-powered sensors with a variety of applications in addition to powering wireless sensor nodes sustainably. This paper presents a study on sustainable power generation based on the footstep utilizing a piezoelectric sensor. The harvester is made up of a piezoelectric oscillator that is self-biased to control the transistor's switching frequency and amplitude in the boost converter. This device enables the controlling of the output DC voltage in a simple manner that does not require any biasing external source. Piezoelectric-Based Footstep Power Generation Systems can play an important role in providing energy to smart cities. This research highlights their contribution towards sustainable smart cities while offering a blueprint for integrating footstep power generation systems into urban infrastructure.

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1   Introduction

Smart cities perform a significant task as innovation triggers for enterprises in various sectors, including health, environment, and information and communication technology. Future smart cities will use smart innovation ecosystems to raise residents' standard of living in general [1–3] in the situation of smart cities, it is suitable to address issues such as the Internet of Things (IoT), smart homes, sensors, and controllers are pertinent practically everywhere. The benefit of IoT is that it enables quick and wireless connections between objects, improving communication and monitoring primarily [4–7]. With respect to a Smart City, sustainability is an essential concern. Researchers are challenged by the complexity of replacing fossil fuels to investigate new renewable, sustainable, and green energy generation techniques. Green energy is conceptualized as a sustainable and alternative source at the same time, being one that comes from renewable sources with no or very little environmental effect. With expanding daily demand, electricity has currently turned into a lifeline for the populace. Modern technology demands enormous amounts of electrical power for its many functions. The production of power is the leading cause of emissions worldwide [8, 9]. As a result, the development and responsible use of alternative energy sources have been perceived as increasing worry over the gap between the supply and demand for electricity. On the other side, as the world's population continues to grow, the demand for energy is rising linearly every day. In addition, the gap between supply and demand for energy is rising exponentially. For this reason, researchers and innovators in the field of energy collecting are investigating viable applications for renewable energy sources [10]. In recent decades, power generation and distribution have become integral components of daily living. As the demand for petroleum products skyrockets, it will eventually become impossible to produce energy using non-sustainable power sources. The condition and economy are also being forced by this overconsumption and its associated risks. This level of CO emissions and greenhouse gas absorption into the atmosphere has led to concerns about increasing ocean levels, rising average temperatures, and unfavorable weather conditions. Unexpectedly, as modern technology and devices become more prevalent, there is an increase in the demand for power supply [11]. Unfortunately, oil fuel generators, which are outmoded and unreliable due to the significant environmental damage they inflict, are the primary source of electricity today. So there is a huge need for an oil fuel generator replacement that is intelligent, clean, dependable, and less polluting. For future sustainable cities, a smart grid that can manage erratic power supplies will be required. Utilizing as many locally available renewable energy sources as is practical is one of the main objectives. Numerous researchers have shown interest in small-scale energy-harvesting devices like vibration-based harvesters over the years. There are several motion and vibration sources in smart cities that could be used for energy harvesting [12]. The direct conversion of kinetic energy from human motion, wind and air pressure, vehicles, ocean waves, water pressure, buildings and structures, bridges, and roads into electrical energy is made possible by piezoelectric energy-harvesting systems. One of the potential sources of energy in smart cities is

human movement. Humans execute walking more frequently than any other activity because it produces a significant amount of displacement. To capture the energy generated by walking, piezoelectric materials have been developed. These materials can either be incorporated into shoes to harvest energy from human weight, or they can be attached to the leg or foot so that the energy harvester can be excited by a walking or swing motion. Piezoelectric energy, which produces consistent energy by transforming mechanical energy (applied load) into electrical energy and voltage, is one of the most effective and clean energy sources [13]. When a mechanical stress is applied, such as when the substance is squeezed or stretched, a piezoelectric substance produces an electric charge. Piezoelectric energy harvesters hold great promise for generating power from ambient vibration sources. They offer the benefit of transforming mechanical strain into electrical energy without drawing any more power, have a huge power density, are simple to use, and can be manufactured at various scales. If the resonance frequencies of piezoelectric energy-harvesting systems coincide with the excitation vibration frequencies, they can output their maximum amount of power. Microelectronic devices may use this electrical energy or batteries may store it. The transition of vibrational energy from the environment—generated by human motion, air flow, and water current/wave—has been the subject of numerous studies. Footstep Power Generation Using Piezoelectric Sensor is presented in this study. The harvester is made up of a self-biased piezoelectric oscillator that will be used to regulate the boost converter transistor's switching frequency and amplitude. This gadget makes it simpler and unnecessary to use an external source for biasing to control the converter's DC output voltage.

2 Methodology

A piezoelectric layer, or beam, is attached to a vibrating mechanical component in a piezoelectric energy harvester's basic construction. In this piezoelectric layer, the vibration creates bending (stress), and the stress in turn induces electric charges. It is common practice to add a proof mass to the end of a piezoelectric beam in order to convert the vibration—or, more accurately, acceleration—into an effective inertial force that will increase the beam's bending. The mass can also be changed to adjust the structure's effective resonant frequency to the frequency of vibrations, hence increasing output power. The developed system comprises of three major elements which are: input, process, and output. Figure 1 depicts developed system's block diagram.

Piezoelectric sensor, LCD, ARDINO UNO, battery, LED, rubber pad, bridge rectifier, and connecting wires are all parts of the constructed project. In any area where we have tiles with piezoelectric sensors, the energy or force is supplied by human stepping. The hardware and software components of this project are combined during the implementation phase. The usage of a foam cushion in this instance, as can be seen in the Figure above, is done to prevent the Piezo sensors from disintegrating under load. As illustrated in Fig. 2, the boot loader has been pre-programmed into the Arduino

Fig. 1 Block diagram

microcontroller to make it easier to upload these programs to the chip's memory. The UNO Arduino, an optiboot type device, serves as the boot loader by default. The boards have program code loaded to another computer via a serial link. Some serial Arduino boards employ a shift registers logic circuit to convert between RS-232 logic and transistor-transistor logic. The modern Arduino boards were constructed utilizing a USB-to-serial FIDI FT232 chip and were programmed using a universal serial bus. The Arduino board's structure comprises of numerous controllers and microprocessors, as well as a collection of analog/digital input output pins for connecting to other development panels like shields and other circuits in the system. Furthermore, a number of models' serial communication interfaces, including USB, are utilized to load software from computer devices. The microcontrollers have traditionally been programmed utilizing the dialect features of the C and C ++ programming languages.

By using the concept of mechanical vibration, the piezo sensor turns the applied force into voltage. This sensor essentially transforms kinetic energy into electrical energy types. sensors array should be linked serially mode in order to produce a sufficient amount of electrical power. The two types of sensors that are readily accessible on the market are PZT and PVDF, and they are both coupled to filters to regulate the output voltage of the sensors, as illustrated in Fig. 3.

Fig. 2 Platform of Arduino type UNO

Fig. 3 Piezo sensor
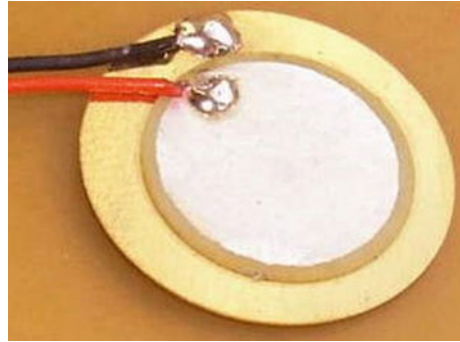
A booster type utilized as a DC/DC power converter is the step up converter. With this converter, the input voltage is increased while the output load's current is decreased. This converter's switched mode power supply class includes transistors, diodes, and energy storage components like inductors and capacitors. To reduce voltage ripple, an inductor or capacitor combination circuit is included as a filtration component. This kind of converter is depicted in the system shown in Fig. 4. Here, a boost is being employed to increase the piezoelectric transducer's erratic voltages.

The switching circuit and Bluetooth module are shown in Figs. 5 and 6, respectively. The Switching circuit enables the Arduino to manage the system's power flow. When to permit and not permit a given level of electricity to pass through can be determined by the Arduino's programming. The permissible voltage in this situation is 3.0 V. The Bluetooth module type HC-05 has been utilized in this system, and once the system reaches a charge point of 3.0 V, it permits the switching circuit to let electricity flow through and recharge the battery at its normal voltage level of 3–5 V.

The compiler type IDE is a cross-platform tool created in the Java programming language for Processing with the aim of introducing artists to computer programming and software development. This required the use of the code editor, syntax highlighting that matched, and automatic indentation that can upload and build the program to the panel with just one click. The electronics type that can be employed as an inaccessible organization for a particular remote entity is the universal android

Fig. 4 DC–DC buck converter

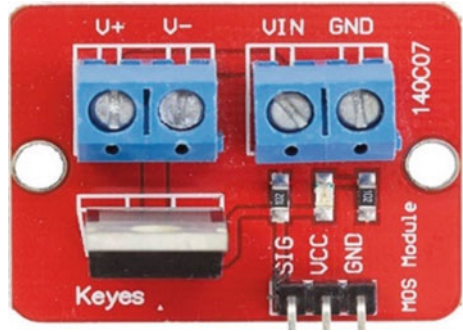**Fig. 5** Arduino switch circuit

Fig. 6 HC-05 module

software used to show and control the data transfer via Bluetooth. Comparing this component's interface design to that of other software applications, it is easily adaptable.

The Proteus framework is under constant development, turning into efficient, affordable, and marketable EDA packages. Its embedded co-simulation program, called VSM Proteus, combines animated components, a microprocessor model, and mix mode SPICE simulation to make it easier to simulate an entire microcontroller. After several attempts, it was discovered that the Piezo Sensors must be placed in order to absorb the most kinetic energy possible from the weight of the footstep, as illustrated in Figs. 7 and 8. This was discovered during the design phases of the stepping mechanism. Thus, after numerous experiments, the star-shaped 14 piezo design was selected to replicate the movements of the heel and forefoot as people walk, as seen in Fig. 9.
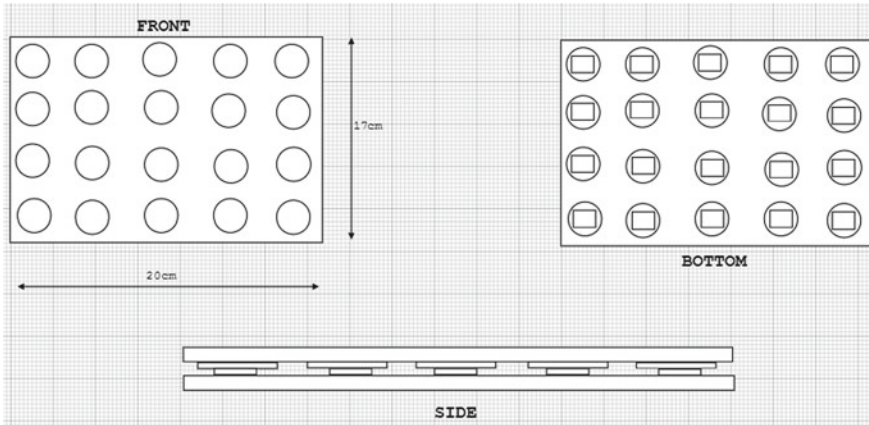
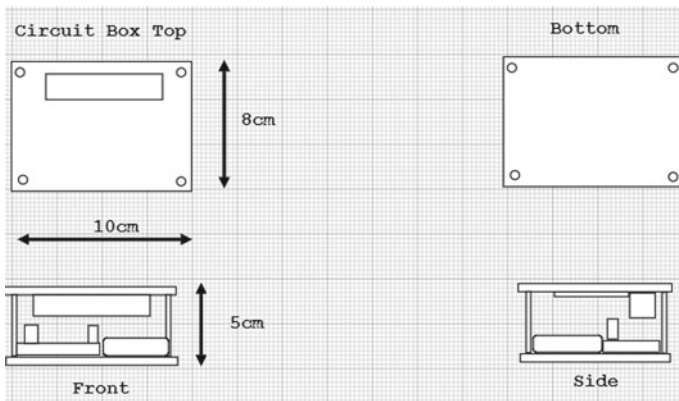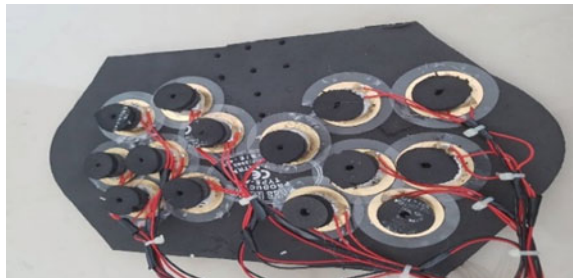**Fig. 7** Illustrating final design for the stepping mechanism

Fig. 8 Case design for circuitry

Fig. 9 Piezo placement on foam pad

3 Result and Discussion

Simulations on this system must be run in order to confirm the viability of the proposed design. This would also allow us to confirm the dependability of the above-discussed control measures. Figure 10 is a simplified representation of the proposed system created using Proteus software.

A full smart power generation system utilizing piezoelectric sensors has been built for experimental validation and during the prototype development phase. The prototype testing process enables a thorough grasp of how the prototype's features and functionality correspond to the various applied pressures and strains. The voltages created across the piezoelectric materials and the quantity of current flowing through them is measured, respectively, using voltmeters and ammeters.

Different voltage readings were recorded that corresponded to the various pressure and strain readings as they were tested on the piezoelectric material. The capacitor may be charged to store energy, and depending on the situation, it can also be discharged. Nevertheless, this circuit's ability to capture energy is not very significant. Just after the bridge rectifier phase, a DC to DC converter can be used to solve this issue. The installation of a DC–DC converter has proved to increase energy harvesting by a factor of seven. It includes a switching mechanism that is connected in parallel to the piezoelectric element (Fig. 11).

The interface of Blynk's mobile monitoring app is shown in Fig. 12 for determining the level of battery voltage for the output voltage of the piezoelectric sensor attached to the piezo transducer.
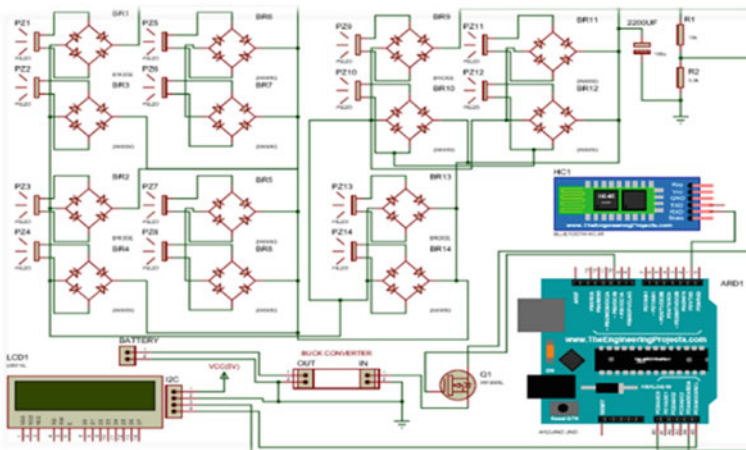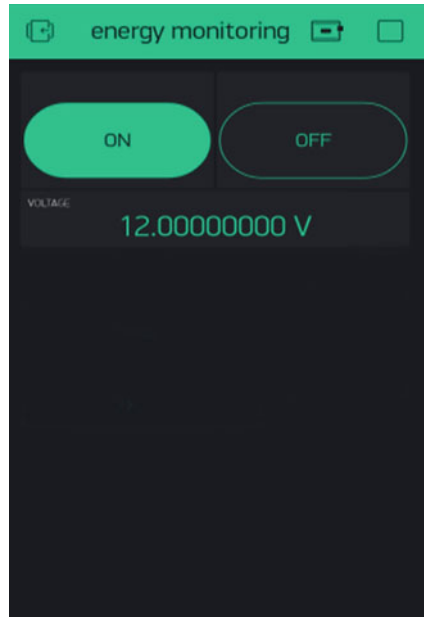

Fig. 10 Circuit diagram of pizoelectric power system

Fig. 11 System under. **a** Minimum load and **b** Full load

Fig. 12 Output voltage of the battery connected from the Piezo transducer

4 Conclusions

By utilizing technology to manage the available resources, smart cities seek to improve the life quality of residents. Applications that have been implemented in such cities and have a lower negative environmental impact include renewable energy harvesters. Because they can power tiny micro-electronic devices and real-time IoT sensors, ambient energy-harvesting sources in smart cities have drawn a lot of interest. Materials that are piezoelectric are excellent choices for this use. This paper presents a proposal for energy harvesting based on the footstep by using

piezoelectric materials. It is an additional strategy for encouraging the implementation environmentally friendly innovations that protect the planet from environmental contamination. Although this study indicates that piezoelectricity in a footstep has good potential for energy harvesting, there are still numerous ways to broaden the scope of this study. According to the proposed technology, piezoelectric materials might convert an independent potential energy into electrical power. The sensors and microcontrollers-based voltage monitoring system of piezoelectric sensor energy generation were effectively integrated into the proposed system.

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