Harnessing Energy from Everyday Life

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Abstract. Renewable energy will drive the future. The applications of mobile phone is no longer limited to communication between each other but can also be used on an everyday basis starting from grocery shopping to watching series for entertainment. Thus our mobile phones require constant charging of power. It is almost impossible to increase the mAh capacity of the battery indefinitely; therefore the need of a battery re-charging source is inevitable. The objective of this research work is to design a sustainable, portable charger in which power is generated with the help of piezoelectric sensors embedded into the shoes of an individual. The underlying principle is to transduce the pressure applied on the piezoelectric sensors to power. This power can be used to charge mobile phones using a USB cable at any convenient time. The light weight compatibility of the device makes it easily portable. In the proposed system, a grid of piezoelectric sensors of suitable size is incorporated in the shoes and an Android application is developed to monitor the power generated as well as to suggest the optimal walking pace for the user to increase power generation. The key highlight of this prototype is that it is user friendly and is paired with an Android application to facilitate maximum power generation.

1. Introduction

In recent years electricity demand has increased drastically but the supply is limited. The stress put upon earth’s non-renewable energy resources has significantly increased. One of the potential alternatives to non-renewable energy is utilizing the mechanical energy from walking or jogging to generate electric power. Regenerative energy established upon the piezoelectric effect holds the key towards effective solutions in harvesting energy from human movements. Harvesting electrical energy through human movement is an attractive way to get clean and sustainable electric power. Nearly all smartphone users wish to have a greater battery life, therefore this idea of charging mobile phones every time they walk is not only sustainable but also an exciting solution for the end users. This process is achieved by using piezoelectric transducers followed by a simple charging circuit. Piezoelectricity is the electrical energy generated by the external pressure applied on piezoelectric transducers. When pressure is applied on an object, a negative charge is created on the extended side and a positive charge on the region where the pressure is applied on the piezoelectric crystal. When the pressure is removed, electricity flows through the material. This energy can be harnessed and processed to meet significant amounts of daily energy requirements.

In general, piezoelectricity is produced by two effects: direct piezoelectric effect and converse piezoelectric effect. Electric power is produced with a direct piezoelectric effect when some
mechanical strain is applied to the transducer. The converse piezoelectric effect is employed in making actuators. Piezoelectric building materials can be either natural or man-made. Quartz crystal is an example of natural piezoelectric material while Lead Zirconate Titanate (PZT) is a man-made material. The objective of this work is to generate renewable electrical energy from mechanical energy.

The novelty in this research includes the usage of piezoelectric sensors instead of already existing electrostatic solutions for harvesting energy from shoes. As cited by A D T Eliot [18] in his paper where he extensively compared the behaviour of electrostatic material and piezoelectric material, it is evident that electrostatic materials are preferred only in less acceleration environments. Better performance is showcased by piezoelectric devices because of increased conduction losses compared to electrostatic devices. One other existing solution for energy harvesting is magnetostrictive actuators. The reason why piezoelectric sensors were chosen instead of magnetostrictive actuators is because it can be easily embedded into a smart grid-like structure and also is widely available as compared to the magnetostrictive actuators [19]. And also, there have been attempts in working with the piezoelectric sensors to generate electricity from the sole of shoes as experimented by Rohit Rajput [20]. On the contrary, they have experimented by using a single piezo sensor whose output voltage is very low. A transducer needs to undergo a bending process in order to optimize the voltage generated by it as cited by Anis Maisarah Mohd Asry [21]. Hence a 3x2 grid array of piezo sensors was proposed in order to maximise the output voltage. In addition, a battery charging circuit is also included using cost effective materials and the behaviour of the design is observed and reported above under different parameters.

The next section briefs about some similar works and is followed by design and working of the proposed system, results and discussion, conclusion and future works.

2. Related works

There have been some recent researches carried on to design a system to build potential applications that harvest energy using piezoelectricity as an alternative for non-renewable energy [1]. The prototype in [1] was assessed using haptic finger force and water droplets. The first test used one finger to press on a randomly selected piezo sensor. The generated voltage using finger force depends on the discrete force of the fingers and the frequency in which the pressure is applied. When more fingers press on several piezoelectric sensors simultaneously, it is expected to harvest greater amounts of energy. The resulting relatively small AC power is boosted using an RC coupled amplifier and then converted to DC using a full-wave rectifier. This can be incorporated on music keyboards by installing piezo plates on them to harvest power. Recently, the researchers conducted a study on optimum energy harvesting by simulating a system using piezoelectric sensors pasted on a tile [2]. A piezoelectric energy harvesting system was designed and implemented in an experimental simulation using MATLAB. The conclusion from the study was that obtained output voltage can be further enhanced by the use of piezoelectric materials with high coupling coefficients, enhancing the expanse of the unit area of piezoelectric diaphragm, and by employing piezoelectric diaphragms in series-parallel form. The output could be further raised by a suitable step-up converter. The developed energy harvester in [2] was found to be applicable to support low-power electronic devices like wireless sensors, LED light applications, power supply inside aircraft, and many lower-powered MEMS. The objective of the work in [3] is to acquire a contamination-free fuel source and to utilize the squandered mechanical energy generated from human movement. The study focuses on how mechanical energy is transduced to electrical charge through piezoelectric impact. The working principle and different sources of vibration in the piezoelectric crystal are analyzed.

The basic concept [4] is that when a piezoelectric sheet is pressed, the interatomic distance between 2 atoms gets altered due to which deformation occurs in between atoms and positive ions are produced. During relaxation, the same process occurs in reverse yielding negative ions and due to this alternate
cycle, voltage is generated. A piezoelectric sheet consisting of 16 piezoelectric crystals, diodes, a capacitor, and a lead acid battery was constructed to tap the energy produced by footsteps. It is concluded that the power generated is proportional to the weight applied on the piezoelectric sheet and the running cost is found to be negligible compared to other renewable energy options. Owing to the recent limitations of power sources, energy harvesting has become the area of interest for more and more scientists and researchers. Creation of flexible piezo materials is explored using lead zirconate, titanate powder, multiwalled carbon nanotubes, synthetic rubber, solvents THF, and chloroform. The materials are assessed for several parameters like performance sturdiness, lifetime, etc. under various conditions. The study was undertaken with the motive to extract usable power which may support a number of devices with low power requirements like mobile devices, wireless sensor networks, MEMS etc. The paper focuses on the generation of electricity using the piezoelectric effect and wireless transmission of the energy produced. The design is such that the piezoelectric generator is placed under the sole of the shoes; hence the piezoelectricity is produced using mechanical pressure exerted during walking or running. Then, the power generated is transmitted wirelessly to a mobile device using the principle of evanescent wave coupling. The receiving device rectifies the incoming wave and converts it to DC supply. The output of the DC supply is sent to the batteries of mobile devices via a charging circuit, hence charging the battery. The paper proposes a replacement to the non-renewable energy sources by utilizing the converse effect of piezoelectric materials as a transducer to convert mechanical energy to electrical energy. The proposed system has two metallic plates with piezoelectric crystals between them which will produce an AC voltage. This AC voltage is amplified and passed onto a bridge rectifier for DC conversion. Later the DC voltage is stored in a secondary Lithium-ion battery for future usage.

There has been a study conducted to generate electricity by sustainable techniques. A comparison study of different technologies to extract the kinetic energy of pedestrians has been carried out using electromagnetic, electrostatic, and magnetostrictive materials. The paper provides a mathematical solution for the estimation of the energy that can be generated from human movements. A three-dimensional model of a human knee with two kinds of piezoelectric materials fixed on it is used to validate the correctness of the proposed model. Concludes that humans can generate an average of 13 micro watt power while walking with a modelling error of 4.8% precision. The paper provides a detailed review on the underlying principle and basic structure of piezoelectric energy harvesting techniques. The research milestones achieved, the challenges and the progress of wearable piezoelectricity are inspected. The paper concludes by stressing upon the need of the further research on piezoelectric materials to realize feasibility and industrialization of wearable piezo devices. Proposes piezoelectric energy harvesting as a technique to ensure uninterrupted operation of wearable devices. The prime focus of the paper is mainly in the upper part of the human body. Based on review they conclude that in comparison to other vital locations in the upper limbs, highest power is generated by placing the piezo transducers on the wrist. The paper provides comparison and possible future scopes for this technique by surveying a wide range of possible materials, architectures that can be employed, and devices that can be built. is a review article that focuses on the underlying mechanisms, on-going research theories, methods of sensor fabrication and potential uses of flexible piezoelectric materials. The paper provides a detailed overview of the recent developments made in piezoelectricity and piezoelectric photonics. The elastic modulus of human skin is compared with that of 10 different polymers. Based on the comparative study, it is concluded that LA/PDMS, electro-spunPVDF, and ZnO/PVDF have higher elastic moduli than that of the human skin and are thus more befitting for wearable devices. When electrical outputs are considered, polarized cast film is found to possess stronger piezoelectric property than electro-spun filament materials.

In various piezoelectric and transducer modifications are discussed. The performance parameters of the various piezo-electric harvesting systems have been reviewed and the scope of the development of existing systems has been discussed in this manuscript. This paper focuses on two distinct symptoms: one focuses on generating more energy and the other focuses on the comfort of the user. In addition to it, a power collecting interface or activity tracker is released and portable sensors are
enabled. An advanced methodology has been introduced in [15] to utilize the power generated by an IC and expand it with a converter. It gets a controlled output of charging smart phone batteries. The charging cycle is examined with an advanced system and the model is designed and tested study power output. A prototype was developed in [16] for power generation using floor tiles. To ensure an uninterrupted, off-grid supply even when there is not much human movement, the method in [16] installed a solar panel in conjunction with the new type of floor tile power by a PZT based mechanical vibration energy harvester.

The conclusion drawn from the comparative study was that piezoelectric materials are more feasible and reliable compared to the other technologies especially for energy extraction from pedestrian movements as it is more flexible for this application.

3. Circuit design and working

The piezoelectric transducer produces short pulses of current that cannot be easily measured. Therefore a piezoelectric energy harvester is employed to measure and calculate the amount of voltage that can be harvested. Generally, a piezoelectric harvesting circuit, with at least one bridge rectifier is required. The full-wave bridge rectifier that converts AC to DC is ideal because piezoelectric material generates AC but the battery only consumes DC. For each set of rectifiers, a bridge rectifier is used to prevent flow back of current.

Piezo sensors which are 10mm in diameter and 2mm thick are used. And the size of the 3x2 array is expected to be 42mm long and 29mm wide. The gap between each piezo sensor is approximately 3mm and the same gap is maintained in the beginning and end of the array.

\[
\text{Length} = 10 \times 3 \text{(piezo sizes)} + 3 \times 2 \text{(in between gaps)} + 3 \times 2 \text{(gaps in the ends)} = 42 \text{ mm or 4.2 cm}
\]

\[
\text{Width} = 10 \times 2 \text{(piezo sizes)} + 3 \times 1 \text{(in between gaps)} + 3 \times 2 \text{(gaps in the ends)} = 29 \text{ mm or 2.9 cm}
\]

It is approximately 4.2 cm long, 2.9cm wide and 0.2 cm thick which makes it convenient to be embedded in the sole of a shoe. Considering the shoe dimensions, the optimal configuration for the piezoelectric charging circuit was found to be a 3x2 grid of piezoelectric sensors with three full-wave bridge rectifiers connected in parallel. It is observed from simulation results that even if the number of piezoelectric sensors is increased, there is not a very significant change in the output voltage. The circuit is then connected to a 100uF capacitor. It is responsible for limiting the voltage and stabilizing the ripple output of the piezoelectric material. The capacitor will then get charged. Additionally, the capacitor helps in solving the ripple effect that occurs during the AC to DC conversion.

The acquired output from rectifier is then fed into a voltage regulator circuit to obtain a better stabilized output voltage. The generated 5V output can either be stored in a battery or directly used to charge a mobile phone via a USB cord. The LED lights in the circuit are used to indicate that charging is taking place. Figure 1 is the proposed circuit of the system. The Proteus software is used for the circuit simulation. Figure 2 is the Proteus circuit simulation.
The piezoelectric grid and the charging circuit are placed near the heel of the shoe where the sole is thickest. A lithium-ion battery is connected in the position of the plug. When a person steps wearing this shoe, initially for the first few steps the circuit does not fetch current since the capacitors are uncharged. Once it happens, the current generated from the grid of piezoelectric sensors goes into the discharging circuit. The discharging circuit has a voltage regulator which regulates the supply to give a fixed constant voltage. The output current can be directly used to charge a small electronic device or it can be connected to a rechargeable lithium-ion battery that stores the charge and works as a power bank when needed. The circuit when mounted on a shoe underneath the sole, remains durable and replicates the results shown in the simulation with no significant change in the output power. In future, the shoe can be tested in a controlled environment to check the durability and comfort of the system for long term usage.

4. Android Application Development

The product is integrated with a mobile app to make it more accessible, easy to use, and more manageable. The Application developed so far is supported by mobile devices which have Android 7.0 or higher. The App is developed in Android Studio using JAVA and XML languages.

The latest version of the App has following features:
- Measure the number of steps taken by the user.
- Detect the type of steps taken, i.e., Walking, Jogging or Running
- Pair with the smart shoe via Bluetooth
- Calculate total distance covered, average speed and calories burnt by the user.
- Calculate the estimated amount of power that could be generated by the user in a particular session of walking/jogging/running.
The average speed of the steps is calculated and the total steps are classified as normal walking and Jogging/Fast walking for the user to keep track of. These modes are detected since the output power depends on the frequency with which piezo sensors are compressed and released. The total distance covered by the user is also displayed. The app uses Sensor Manager API to get the data from the accelerometer and gyroscope of the phone and uses it to detect the number of steps and the type of steps. The measured values are recorded in an array list from the acceleration sensor. If the recorded values are greater than 25 then it is started again from first. A user defined function is used to calculate the vector length and unix timestamp for the recorded class and the calculated values are returned to the class. For the power calculation part, a formula has been developed to calculate the power generated depending on the number of steps and the pace of steps. The power generated is directly proportional to the frequency of steps taken. Hence, for running the power generated will be more than that of brisk walking. The proportionality constants for each mode are different. The end result is the summation of power guaranteed by each mode. The Android application is created using Android Studio 4.2 software and includes the following modules: System Clock, ArrayList, Collections and Comparator. The Github link for the source code of the Android application generated is [17].

4.1. APIs used

4.1.1 The Sensor Management API. The sensor management API is used to keep track of which sensors are active in a given application. The API enables a sensor device to register with the sensor management and an application to search for sensors that have been activated. It is designed to communicate between the app and all of the device's sensors. SensorManager enables access the sensors in a device. An instance of the class is obtained by calling Context.getSystemService() with SENSOR_SERVICE as the argument. Out of various sensors from the device which can be accessed via sensor manager, data collected by the accelerometer was the main focus.

Using the getX(), getY() and getZ() functions the accelerations from the x,y and z axes are taken. The algorithm is such that if the resultant acceleration vector at a given instant matches that of a defined threshold of walking, jogging or running, the counter will make an addition to the respective type of movement. Thus the app counts the number of steps and at the same time detecting whether the user is walking, jogging or running. In addition to this, the getTime() function continuously measures the time duration. Using this information, distance covered by the user is calculated. In order to calculate the power generated the direct proportionality relation between the power generated by the piezo sensors and the frequency of steps taken is taken. Hence, the power generated is more during running than jogging and walking.

4.1.2 Bluetooth API. Android Bluetooth APIs allows devices to communicate wirelessly with other Bluetooth devices by accessing Bluetooth. Thus, in our case they enable communication between the mobile device and the smart shoe. To use Bluetooth in our application, two permissions were declared. One of the permission declared is BLUETOOTH. It is needed to perform any communication via Bluetooth, such as requesting and receiving a connection, and sending information. The other permission that was declared is ACCESS_FINE_LOCATION or ACCESS_COARSE_LOCATION. Bluetooth can be used to get data about the user's whereabouts so the location permission is needed. In the next step the Bluetooth is set up. After the adapter is found, Bluetooth of that device is enabled. For this the system UI shows the user a dialog box which requests user for granting the permission to enable the Bluetooth. If the permission is granted, the system enables Bluetooth, and focus gets shifted to the Android application when the process is complete.

4.2 User Interface (UI) The UI of the app is designed to be simple and informative. A toggle button has been provided using which the user can easily activate and deactivate the pedometer. The number of steps and distance covered and the types of steps are shown live in real time. Rest all the details like calories burnt, power generated etc are shown as soon as the user terminates that particular session using the toggle
button. The main highlight of the app, i.e., the Power generated section is kept in the middle. The button to pair the device with the smart shoe is also placed at the center.

5. Result and Discussion

From the circuit simulation, the results show that the battery charging circuit was able to generate a solid voltage of 5V after full charging. The typical output voltage of most cell phone chargers is in the range of 5 and 12 volts. Therefore, the power generated can be very well used to charge a cell phone. Figure 3 is the voltmeter output of the simulated system.

![Simulation results for the implemented system (Voltmeter).](image)

*Figure 3. Simulation results for the implemented system (Voltmeter).*

In the android application developed, every time the ‘Activate Pedometer’ button is pressed, the app starts counting the steps and uses it to calculate the calories burned and the average power produced by the system. The counting stops once the ‘Stop’ button is pressed. The average speed of the steps is calculated and the total steps are classified as normal walking or jogging/Fast walking for the user to keep track. The total distance covered by the user is also displayed. Figure 4 is the sample image of the Android application.

![Sample image of the Android application.](image)

*Figure 4. Sample image of the Android application.*
6. Conclusion

From the simulation results, it can be seen that a solid voltage of 5V can be generated and is concluded that the proposed system is efficient enough to use in real-life applications. The Android application created will help to keep track of the power generated and will allow the user to calculate the number of steps to be covered to charge a particular device. In the current digital world, with an increased need for energy resources and eventually, an increased strain put on the non-renewable energy sources of earth, a pollution-free, eco-friendly, renewable, and inexpensive solution is proposed. The daily energy requirements such as mobile phones can very well be satisfied by this innovation while also encouraging the users to walk or jog more. With the recent awareness of physical exercise, the system will be a matter of interest for many fitness enthusiasts. This system has the potential to replace the power banks or charge the power banks. The future scope of the project includes the possibility of pairing the smart shoe with the Android application using Bluetooth. Motivation to walk more and produce more power can be provided by giving rewards to the user via the Android app. The charging circuit can be further extended to store the produced charge in a battery. The proposed android app can be developed further to provide the pairing option: connecting the smartphone directly to shoe sensors via Bluetooth.

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