Future's Sustainable Temperature and Energy Project (S.T.E.P.)

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Abstract

Renewable energy development has been growing to a new focus on industry and research. Harvesting energy from human activities is a clean way to generate power. The benefit of using this energy is apparent: sustainable, no pollution, and low cost or even free. This work presents a floor panel that is able to harvest energy from pedestrian's footsteps and convert it into electricity. The energy generated is used to power a display that grasps pedestrians' attention so that they are aware of the amount of energy that can be produced by just human footsteps alone and how the energy can be put to use.

The proposed floor panel is consisted of following three major stages: a power generation panel, a power conditioning circuit, and a display system. The power generation panel converts the mechanical energy from pedestrians into electric energy using piezoelectric devices. The power conditioning circuit rectifies the electric energy generated and stores it into a battery for powering general applications. Then the display, which is powered by the battery and constructed with LEDs, is designed to show pedestrians useful information and bring awareness of sustainable energy among them. Specifically, the temperature information of the surrounding is shown on the LED display.

1. Introduction

Energy harvesting is defined as gaining energy from passive devices. Exploring new energy trends will help contribute to a long lasting sustainable future. Energy utilization in particular is becoming a leading trend in our economy due to the large increase in global population and energy demand. [1] With our vast growing economy, new energy technologies such as energy harvesting and energy delivery have become a vital concern to researchers. Developing low powered devices, such as a piezoelectric energy harvester, will promote development of micro power generators that replace conventional power source. [2] [3] Our goal as a research team is to utilize some of these new energy technologies to produce efficient low powering techniques.

In engineering and applied science fields, piezoelectric materials are essential in vibrational based energy harvesting technologies. The piezoelectric phenomenon is a property of certain materials when physically deformed in the presence of an electric field, or to produce an electric charge when mechanically deformed. [4] Piezoelectric ceramics induced an electrical current that can be channeled into an electrical storage. Placement of the piezoelectric materials in different arrangements will further optimize the total energy generated. This configuration could accumulate considerable amount of energy as time goes by. Once the energy has been generated, the current could be efficiently rectified to power low power DC applications.

We propose a specially designed floor panel that is able to harvest mechanical energy when pedestrians step on it. The energy generated could potentially power low power applications such as lighting systems. The main purpose of this project is to further research and develop an energy harvesting system to be implemented into a flooring system. Piezoelectric material offers a solution of implementing these devices into a flooring system to harvest wasted mechanical energy from people walking across our flooring system, and convert that into electrical energy. When installed in a large scale, the piezoelectric energy harvesting floor system could generate significant clean energy to replace conventional energy source.

In this project, we developed a floor panel that can harvest mechanical energy and implemented it in the front of the engineering building of Central Michigan University. The panel then powers a LED display that shows the temperature of the outside building. A LED thermometer was developed as an example of useful electric applications. We used LED display system because it brings direct visual impression to pedestrians and draws their attention. It serves as an attractive device that brings people awareness how wasted energy could be potentially used. We propose to implement electric generators (piezoelectrics, in particular) into the floor and aim to further advance the development in technology in the alternative energy movement.

2. System Design

The whole system has three main subsystems: power generation stage, power conditioning stage and display application stage. The system will be first converting mechanical energy into electrical energy, storing the electricity, and then using the electricity with display applications. These sub system functions can be summarized in Figure 1. Each subsystem is elaborated in the following sections.

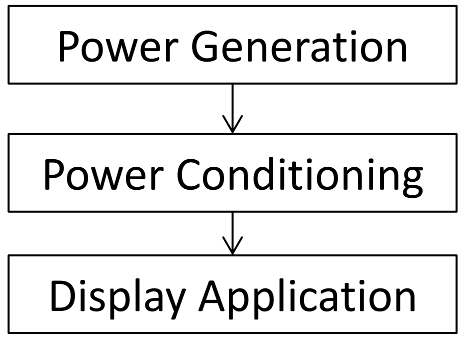


Figure 1. System Overview.

2.1 Power Generation

The power generation stage harvests energy from walking pedestrians. It utilizes a specially designed floor panel to convert the mechanical energy into electricity. In this project, the penal is implemented in the front of the engineering building at Central Michigan University. The panel consists of square tubing walls with multiple Lead zirconate titanate (also known as PZT) tabs along the wall parallel to the ground and fixed at one end. As a piezoelectric material, these tabs generate charge flow when being deformed. The tabs are displaced from a ring that is attached to the top of the panel. When pedestrians step on the floor panel, the top of the panel comes down, displaces the tabs down, and is then released. This causes the tabs to vibrate, allowing energy to be generated for a short amount of time. This is a great advantage because the longer the tabs vibrate, the more electricity is generated. This system has less overall PZT material, but overall stronger connection because of the ready to use tabs that have clamped pins attached to each side of the material. The tabs are configured intertwining each other to optimize the quantity of tabs that can be placed in the system. (Figure 2 and Figure 3).

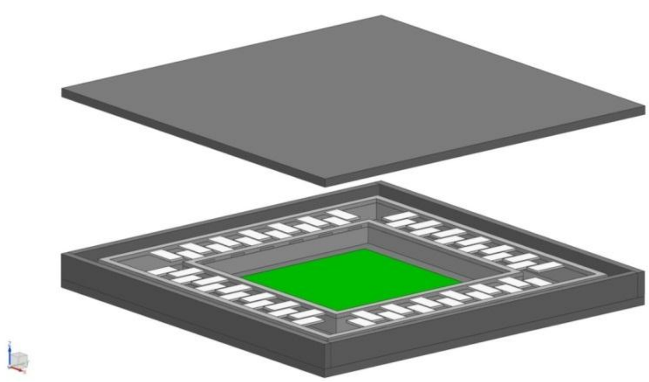


Figure 2: floor panel design

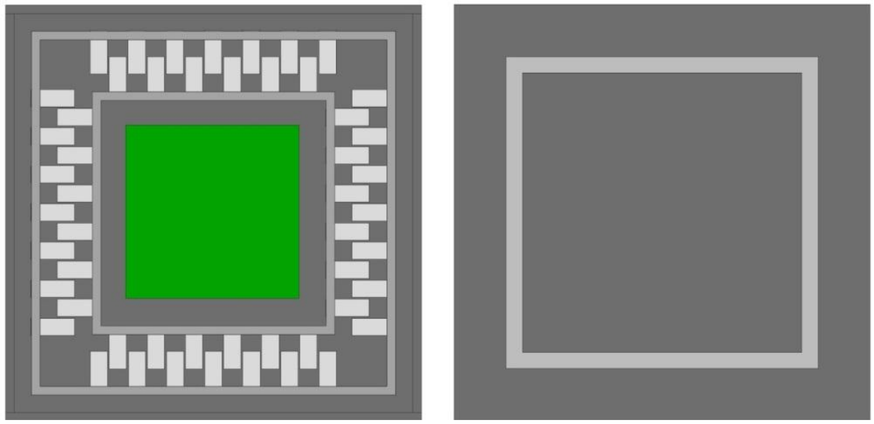


Figure 3: Floor Panel Opened Up

2.2 Power Conditioning Design

Electricity from the power generation stage comes in an irregular alternating current (AC) form. This form of electric energy cannot directly being used by most electric applications. The power conditioning stage rectifies this current and stores it into a battery bank, so that the energy can be utilized in common applications. The power conditioning circuit consists of a full bridge rectifier using diodes connected to the outputs of the PZT tabs. These tabs are in parallel to produce the desired voltage and current. This functions as the input for the next stage, Flyback converter, which includes two aluminum electrolytes and two ceramic capacitors. The Flyback converter functions as a highly efficient AC/DC converter stage that further conditions the input to a static DC current. The Flyback converter is mainly developed from a commercial integrated chip with help of a simple switcher. [2] This chip allows us to control the duty cycle of the converter for maximum power transfer. [5]

2.3 Display Design

Along with the power generation and power conditioning stage, a LED display system is designed. The display serves as an example for potential useful electric applications. It not only shows pedestrians the temperature outside the building, but also brings awareness of sustainable energy around them. The system consists of a large thermometer that is a LED bar consisting of 50 green, yellow and red LED bulbs. From the bottom to the top, 17 of them are green, 17 of them are yellow and 16 of them are red. The thermometer shows the outdoor temperature with an analog present.

Following in Figure 4 is a detailed design of the LED display. To minimize the control line, the dot-matrix idea is used in the LED display design. This configuration ensures that only one LED is lighted up at an instance. There are 5 rows and 10 columns, in total 50, LEDs. Each row and each column is controlled by a digital output from the LED driver. When multiple LEDs need to be on at the same time, the LEDs are lighted up one by one at a high frequency. Since the frequency is too high, usually higher than 60Hz, human eyes cannot detect flashing of the LEDs and assuming they are on continuously.

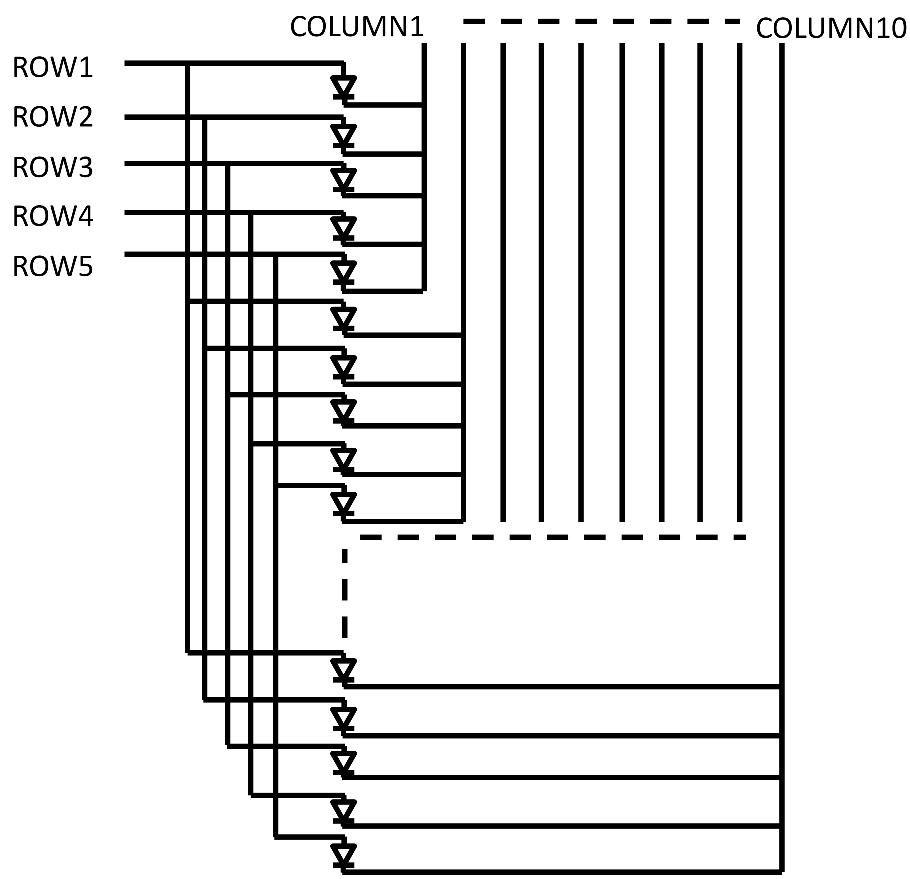


Figure 4: LED configuration

3. System Analysis

This section provides the analysis performed to design the system fitting the requirements. Mechanical calculations, power conditioning analysis and display analysis are carefully conducted.

3.1 Mechanical Calculations

3.1.1 Maximum Load on Panel Analysis

To analyze the parameters and properties of the designed panel, we considered two cases: one person 100lbs and another 250lbs. Assuming the maximum load with a safety factor of 4,the maximum load the panel will be able to support is static load of 4500N. Since people walk with different tread patterns: walking, running and even jumping; the panel was designed for all possibilities. First consider the scenario of walking; when people walk, their striking foot exerts a force 1.13 times greater than their static load. [6] Case one of a 250lb person walking would exert a 1385N force which is less than the maximum designed force. Another scenario is a person running across the panel. When people run, their striking foot exerts a force 1.82 times greater than their static load. [7] Another approach was experimental yielding an added force 1.8 times greater than their static load. [8] Using the maximum between the two, conservative approach case one of a 250lb person running would exert a 2017N force, which is less than the maximum designed force. Final scenario would be a person jumping repeatedly on the panel; conservative estimate would be the force would be 3 times larger than their respected static load of 3325N. Approaching this problem experimentally, the person jumping exerts a force 2.12 times greater than his or her static load. [8] All approaches pass, yielding force smaller than the maximum designed force.

3.1.2 Piezoelectric Bimorph Deflection Analysis

We have decided to use piezoelectric bimorphs PZT materials as the power generating source, mounting them in a cantilever position. This mounting position allows for the maximum deflect, from each cantilever beam. To prevent plastic deformation, and from damaging the piezoelectric components, the data shield recommends not to deflect more than 2mm. Using beam theory equation and solving for the maximum load, the maximum force can be applied to each piezoelectric component is 2N. Limited information was provided for the piezoelectric components mechanical parameters. The provided information contained the modulus of elasticity. With a maximum load of 2N, the beams yield a maximum stress of 144Mpa. Designing the panel around a maximum force of 4500N, the panel needs to have 2250 PZT beams to support the maximum load without an external supports. Since this is not feasible, external supports are used, acting as constraints only allowing the panel to be displaced 2mm.

3.1.3 Panel Force Analysis

Knowing the maximum load the panel can have and the number of piezoelectric components we are placing in the panel, we determined the design for the support walls. The number of components was determined from how many can fit into the panels, 12” by 12” constraints. Summing the forces in the z dimension shows all four outside walls, 4 inside walls that will hold the Piezo components and a negative maximum load each support need to support 551.5N. The outer walls purpose is for the main supports while the insides are to constrain the piezoelectric beams in cantilever position. Each is made from different materials: outside supports from steel and inside supports from plastic. Choosing materials appropriately knowing their yield strength, we determined the minimum width of each support. The outside walls need a minimum width of 2.62 micro meters and the inside needs 0.167mm. These values are not feasible, to build around. Using a width of 6.35mm (0.25in) is appropriate and yield a safety factor of 2414 and 37.8 for each support respectfully.

3.2 Power Conditioning Analysis

With know the power produced from a single PZT, we were able to develop the system from here. Based on preliminary testing result, each PZT tab produces around 20 volts when deformed. Consequently, a voltage step down is performed by the fly back converter to 3.3 volts. Since the PZT's produce enough voltage, we connected them in parallel to increase the current supply. Each PZT tabs produce around .6 µW. With 50 PZT's the system can produce around 0.03 mW. This means we cannot run our system directly from the PZT's, a sleeping mode needs to be developed to turn off the display system when there is not sufficient power harvested.

3.3 Display Analysis

3.3.1 Algorithm

The LED display is a large thermometer constructed by 50 green, yellow and red LEDs. It is controlled by the central controller to display the current temperature, which is measured by a temperature sensor placed outside. A PIC16LF1933 microcontroller is used as the central controller. All the display is activated when a step is detected from the penal, and the controller receives an interrupt. The controller activates only when an interrupt is detected. Following in Figure 5 is a general flow chart of the interrupt algorithm.

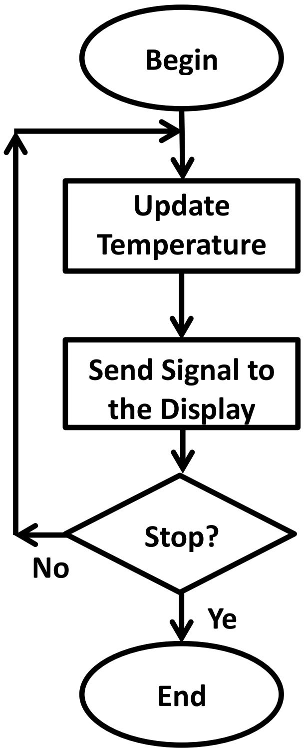


Figure 5: Flow chart of controller

During an interrupt routine, the central controller first updates the current temperature from the temperature sensor placed outside the building. Then, the calculated data are feed to the display drivers. The display drivers use another PIC16LF1933 microcontroller to drive the LED thermometer.

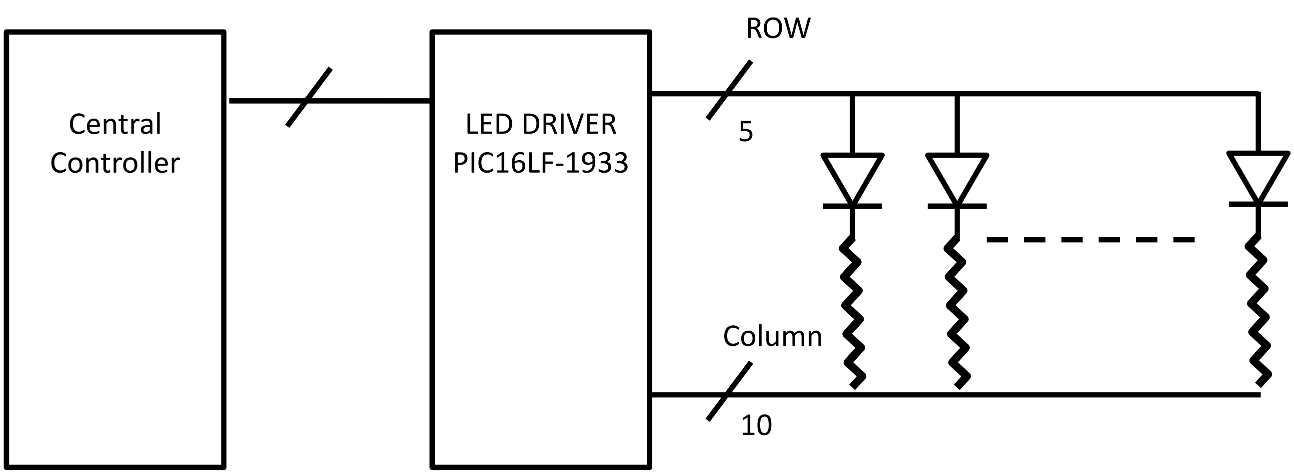


Figure 6: Diagram of LED driver and LEDs

3.3.2 Power Consumption

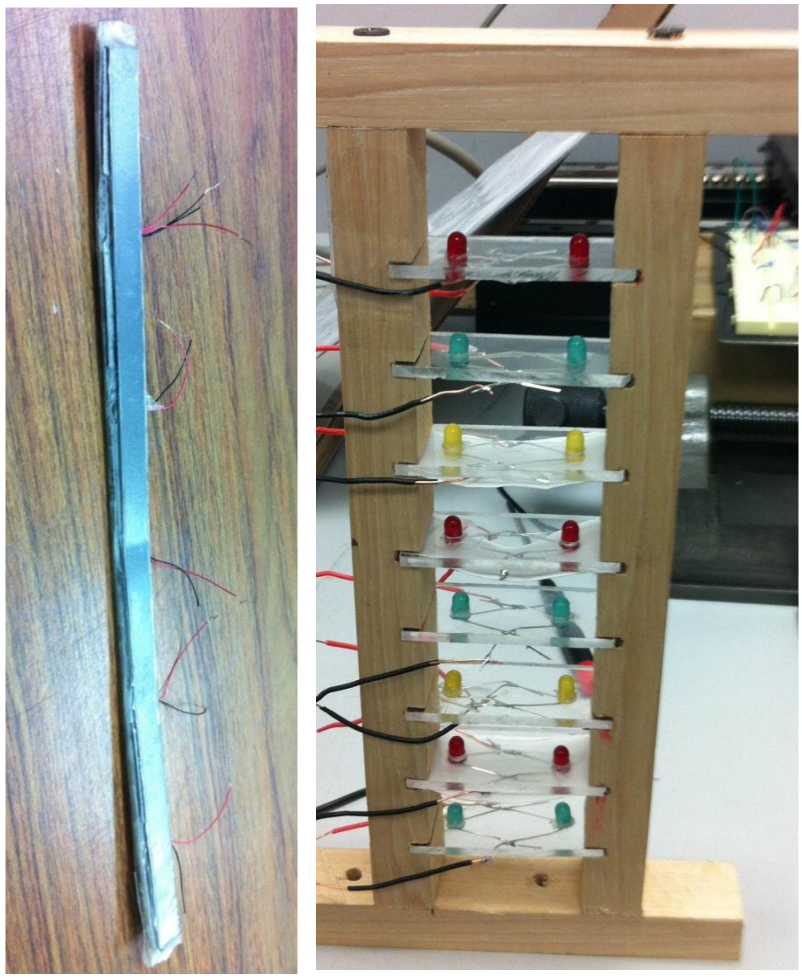
The power consumption comes mainly from the LED display modules. Comparing to 2 mA current consumption of each LED bulb, the central controller and the display driver consume only micro ampere of current. Consequently, the calculation on the power consumption focuses on LED display modules only.

Using low power LEDs, each LED bulb needs 2mA current to light up. According to the data sheet, the red, yellow, and green LED forward voltage is 1.7V, 1.8V and 1.9V. Assuming a 3.3V voltage supply from the microcontroller and 2mA current is passing through the LED, the power consumption of each LED is 6.6mW. Due to the control method of design, only one LED is lighted up at one instance, the total power consumption of the display is about 6.6mW. [9]

Figure 7. Application Placement Location.

4. Preliminary Results

Small scale testing of the piezoelectric, have been complied into cells for easier placement. Relooking at our current application, we noticed possible application under the grate on the supports Figure 7. The piezoelectric have been compiled into a cell that contains five of the components Figure 8 (a). Figure 8 (b) shows a scaled model of the LED thermometer.



(a) (b)

Figure 8. (a)Piezoelectric Cell. (b) LED thermometer

Each cell placed on top of the support, shown by the arrow in figure 8. When the grate depicted in the left figure 8 is stepped on, by patrons walking through the door. The cell is compressed, and the piezoelectric components generate energy. Current output of from one of the piezoelectric components is about .93mW, which consists of five PZT tabs.

This result is promising. Based on estimation, placing 6 cells, or 50 PZT tabs, can potentially generate 9.3mW power, which is close to the power consumption of the display system. This means the display system could be seldom turned off and remained on most time.

The next step the group plan to take is to optimize the LED display system and develop a timing control algorithm to control the ON/OFF state of the LED display. This will prevent from drawing too much power from the battery bank and help maintain the stability of the entire system. Then, the entire system will be installed to the entrance of the Engineering building.

5. Summary

We designed, prototyped and tested an energy harvesting flooring system that can generate electricity from pedestrian walking on the floor. The floor panel utilizes piezoelectric tabs to convert mechanical energy from deformation into electricity stored in a battery bank. Then the power conditioning rectifies the input, and store the energy in a battery bank. Finally, a LED display, powered by the harvested energy, is designed to show useful information to the pedestrian and bring sustainable energy awareness among them.

According to the preliminary result, piezoelectric cells are made and implemented under the grate in the front of the engineering building. The power conditioning circuit stays next to the piezoelectric cells. The LED display is mounted on the window of the front door of the building, an eye catching location. The entire system is independent and need no power supply from the outside. This is a promising result and shows how renewable energy can be used around us. We believe that sustainable energy system will become more widely used and play an important role of our daily life!

6. Engineering Education

This system is an important opportunity to create free clean energy for a sustainable future. This project is an opportunity to take advantage of something that is becoming the young generation's motivation to help reduce our own carbon foot print. The system will be placed in high traffic areas and will be eye catching but not impairing to the walk way. This will raise awareness and it will introduce and inspire young engineers to develop their own energy harvesting systems. These systems will only become more efficient, but will be developed from more less-known sources of wasted energy.

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