Piezoelectric Floor Energy Harvester: A Prototype for Renewable Urban Power Generation

A Project report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

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DECLARATION

We hereby declare that this project "**Piezoelectric Floor Energy Harvester: A Prototype for Renewable Urban Power Generation**" represents our own work which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. We have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety and acknowledged my obligations and the rights of the participants.

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APPROVAL

The project entitled **"Piezoelectric Floor Energy Harvester: A Prototype for Renewable Urban Power Generation"** submitted by **Md Asif Hossain (ID: 213-33-1409), Md Atikur Rahman(ID: 213-33-1414), Md Fahim Tasnim Akanda (Id: 213-33-1426)** has been done under my supervision and accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **October, 2025.**

Signed

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Dedicated

To

Our beloved parents

and Respected teachers

Whose prayers, effects

And wishes are an inspiration

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LIST OF ABBREVIATIONS

AC	Alternating Current
CC/CV	Constant Current / Constant Voltage
DC	Direct Current
FEA	Finite Element Analysis
IoT	Internet of Things
LCD	Liquid Crystal Display
MPPT	Maximum Power Point Tracking
PZT	Lead Zirconate Titanate
PVDF	Polyvinylidene Fluoride
TP4056	Lithium Battery Charging Controller IC
USB	Universal Serial Bus

LIST OF SYMBOLS

Symbol	***Name of the symbol***
A	*Area*
C	*Capacitance*
F	*Force*
I	*Current*
P	*Pressure*
R	*Resistance*
V	*Voltage*
W	*Work*
x	*Displacement*

ACKNOWLEDGEMENT

To begin with, we would like to express our utmost respect to our supervisor Dr. Srimanti Roychoudhury, Associate Professor of the Department of Electrical and Electronic Engineering at Daffodil International University, who has offered us the opportunity to work on an impactful idea and has taken care of every detail of the development of this idea.

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Finally, to our lovely families, we would like to extend our deepest love and appreciate for their endless support, inspiration and encouragement throughout our journey of studying in this institution.

ABSTRACT

This capstone project focuses on a new approach to sustainably generating energy that uses the mechanical energy from people's feet to create electrical energy. The primary goal of the project is to design, develop and assess a prototype tile system that incorporates either piezoelectric or electromechanical system to convert kinetic energy into electricity during foot traffic. The energy will be held in a storage system since the storage devices will be lithium-ion battery or supercapacitors. The prototype energy tile system will either power low energy systems such as LEDs, or sensors, or full charge an array in smaller-scale applications.

In this project, I am addressing an important aspect of the context of the problem of utilizing the mechanical energy in people with high foot traffic in urban areas such as sidewalks, malls, and stadiums with a possible solution. The project also would act on an important aspect of the problem which is to decrease additional reliance on fossil fuels, and work to educate the users about a possible renewable energy approach.Durable design, slip-resistant surface, efficient energy conversion, and a sensor/ microcontroller for monitoring and controlling the energy tile system are my main design consideration in a new energy tile system design.

The project will develop and test a working prototype to test performance relative to energy output, robustness of the system, and practicality in the real world. Major conclusions are anticipated to show the feasibility of deploying such systems on a larger scale - a scalable, low-cost solution for generating energy locally. Success of the prototype will be determined by the ability to generate at least a minimum amount of power per footstep, sustain that performance over time, and demonstrate potential for low-cost deployment.

Keywords: Footstep energy harvesting, piezoelectric sensor, renewable energy, kinetic energy conversion, Arduino UNO, energy storage, sustainable development

CHAPTER 1
INTRODUCTION

1.1 Introduction

The present energy crisis most definitely influences human survival factors related to electrical energy. Most human activities today are supported by an array of devices and technologies that utilize electrical energy as a power source stemming from historically championed technology. Because of this, electrical energy is undoubtedly a necessary component of all human endeavors. Fossil fuel is currently the primary source of power, however it is a non-renewable natural resource with limited supply because it has a finite mass and will significantly deplete if consumed unrestrictedly over time [1]. The environment is negatively impacted by the production and consumption of fossil fuels, which emit carbon dioxide, generate greenhouse gasses [2], [3]. The creation of alternative energy sources is required to meet present energy demands in addition to the rising need for energy and the imbalance between supply and demand brought on by the depletion of fossil fuel supplies [4]. Reducing the reliance on fossil fuels as a primary energy source for power generation requires the utilization of renewable energy. There is no need to be concerned about a shortage of resources because it is a sustainable energy source that is found in nature and may be used for a fair amount of time[5], [6]. In the past few years, numerous large- and small-scale studies have been carried out to create renewable energy sources. Among the advancements in investigation of renewable energy is energy harvest design [7].

1.2 Proposed solution

The prototype must achieve durability and reliability criteria, generate a minimum defined power output per footstep, and show scalability and cost-effectiveness through a feasibility study in order for the project to be considered successful.

The possible solutions to Footstep Energy Harvesting that is given in the Capstone Project Proposal consists of design, testing and developing a thorough m prototype of an energy- harvesting tile. The energy-harvesting tile will convert foot passed kinetic energy into usable electrical energy, as a result of using either piezoelectric or electromechanical engineering principles. This is a concept to reduce dependence upon fossil fuels and develop the previously untapped mechanical energy into usable energy due to foot traffic in urban cities and public places. Stored energy can be used for low energy devices like sensors, charging stations and LED lights.

The main components of the proposed solution would include:

- Design/ Fabrication: create a robust, durable, and non-slip energy harvesting tile.
- Energy Storage: include an effective energy storage device for example- supercapacitors lithium-ion batteries.
- Control and Monitoring: incorporate sensing and microcontroller components for optimizing system and ongoing performance evaluation
- Durability and Efficiency: mechanical durability and maximize energy conversion efficiency.
- Scalability and Feasibility: consider if, and how the technology can be scaled to larger spaces.

1.3 Objectives

The goal of this senior design project is to create a working prototype of a footstep energy harvesting tile that will be able to collect pedestrian kinetic energy and convert it into electrical energy. The focus of the project will be based on the following five pillars:

1.Monitoring and Control: Monitoring and Control, which will integrate sensing and communication, using sensors and microcontrollers to monitor foot traffic and power production.

2.Efficiency and Durability: Efficiency and Durability, which will maximize energy conversion efficiency while keeping the device functional during long term mechanical operation.

3.Feasibility and scalability: Feasibility and scalability, which will evaluate scalability potential for application in urban areas with concentrated pedestrian traffic. The project will be quantitatively measurable with KPIs to track success, including a tile life of more than 100,000 footsteps, 85% energy storage efficiency, and a power output of at least 0.5 Watts per footstep. The results will show whether the prototype can be a viable source of sustainable energy and give practical advice on future enhancements.

1.4 Brief Methodology

Task It utilizes iterative prototyping to design, build, test, and refine a device that will harvest energy from footsteps in a methodical, hands-on manner. This enables incremental, yet meaningful, changes at each step and also helps to bring real-world engineering challenges into the classroom. Step 1 is to come up with a spec like that it shouldn't let you slip and that it should produce a minimum of 0.5W for every footstep. During the design process circuit schematics will also be designed for the acrylic tile, the Arduino-based energy storage system, and the piezo array (using 35mm discs). When you install all of the components - including the monitoring sensors, 18650 batteries for energy storage, and piezo discs linked in parallel - you can test the prototype on an LCD I2C data display to observe energy output and energy collection to find out how well it gets along with external forces. Modifications might involve replacing capacitors or diodes, or using the testing results to optimize the assembly, by adjusting the layout to reduce voltage loss. This flexible methodology of design process includes the previous tests of small configurations on breadboard, but also allows to avoid expensive design failures. The components listed have been carefully chosen for their specific purpose, the clear acrylic provides strength and allows you to see your 18650 batteries (diode unless you plan on using them unsafely) the arduino lets you have programmable control the 35mm piezo discs offering high sensitivity. In addition, the resistors and capacitors of the energy circuit help regulate the output voltage for a consistent and efficient flow of energy. All in all, this structured yet flexible approach is the best course of action to ensure that the final design is durable, high functioning, and appropriate for use.

1.5 Implementation Schedule and Gantt chart

1. Work Breakdown Structure (WBS)

Phase 1: Research & Planning (Months 1–2)

I. we conduct a thorough literature review regarding available piezoelectric energy harvesting technologies to learn about current trends and solutions that already exist.
II. Then we establish the system's technical requirements and expected performance (for example, to have approximately 0.5W output per footstep).
III. After that it acquire any materials needed, such as piezo discs, Arduino microcontrollers, and rechargeable batteries.

Phase 2: Design (Months 3-4)

I. Then create the mechanical structure of the piezoelectric tile using acrylic sheets and an optimized piezo disc layout.
II. Design the circuit for energy harvesting, storing available energy, and monitoring the system.
III. Simulate the expected output of energy before prototyping the system to confirm it will meet the expected performance.

Phase 3: Prototyping (Months 5 - 7)

I Construct the piezoelectric floor tile, which has already been designed.
II Construct the energy storage unit using 18650 cells, diodes and all other necessary components.
III Combine the Arduino-based setup with the sensors and I2C screen to have a live output of voltage and current.

Stage 4: Testing and optimization (Months 8 to 10)

I. Perform laboratory tests to measure real power output and energy conversion efficiency.
II Conduct durability testing to simulate 100,000 steps for tile life and strength. Evaluate lab testing results and refine the design — e.g., piezo spacing or circuit parameters — to enhance performance.

Phase 5: Documentation, and final program (Months 11-12)

We deliver a full feasibility report including a cost-benefit analysis and potential documentation for scaling and usage.
II Systematically conceive a working prototype to demonstrate.
III. Submit final project documentation including testing data, design files, and results summaries and r[...].

1. **Gantt Chart**

Table 1.1 Gantt Chart

Task	Month 1–2	Month 3–4	Month 5–7	Month 8–10	Month 11–12
1. Research & Planning	■				
2. Design		■			
3. Prototyping			■		
4. Testing & Optimization				■	
5. Documentation					■

1.6. Structure of the Report

1. Summary

We summarize the primary goals of the project — developing an energy harvesting technology powered by a user's movement, its relevance for sustainable energy innovation, and the wider context of the project aims at creating an operational prototype. We completed during months 1-2 of the Research & Planning period

We recap the concept of piezoelectric technology, and its context with respect to global energy concerns. We laud unused energy production via short pedestrian transportation as a possible renewable form of energy production. We propose measurable goals of an 85% efficiency and 0.5W/footstep.

2. Review of Literature

We summarize the existing literature on piezoelectric energy harvesting, energy storage techniques, and global activities connected to the targets above. Completed during months 1-2, and updated throughout the course of the project.We describe the essential functioning mechanism and behave of materials.
We summarize evidence (PaveGen etc.) such as PaveGen tiles in London and other projects.
We identify the barriers of cost, and efficiency seen.

3.Approach

We describe what materials, tools, and procedures you followed to develop and test your prototype (e.g., Arduino-based piezoelectric setup).Drafted during months 3-4 of the Design Phase, and adjusted for post-testing conversations, assessments, and opportunities for changes. We continuously improve on the iterative prototyping process that we are developing. The devices also include schematic diagrams of the harvesting circuit, and monitoring circuit. Lastly, we report on the method for measuring the power output and durability.

4. Design and Implementation

We account for the entirety of the mechanical and electrical design of the prototype including how it was physically realized. We recorded the description during months 5-7 of the Prototyping Phase period. Preceding the plan to cause motion of the system, we designed the acrylic base for the particular arrangement of the piezoelectric discs. We also used a combination of 18650 batteries, and a charge controller, to make the harvested energy available. And we incorporated Arduino with a small I2C display to allow us to monitor the voltage and current output.

5. Testing and Results

We provided factual information regarding the testing of the prototype, its optimization, and the overall performance of the mechanical footstep power harvester. We recorded any facts during months 8-10 of the Testing & Optimization phase. We captured the voltage generation and storage efficiency per footstep. We simulated 100k footsteps to examine its long-term reliability. We measured voltage drops and responded to them while stating what was determined about the reasons for those drops.

6. Feasibility and Scalability Analysis

We assessed the feasibility, cost, and potential future use in real-world settings of the power harvesting system. We accounted for all cost during the months 11-12 of the Documentation phase. We reported summative material cost inclusive of potential ROI. We documented potential applications in highly trafficked urban areas. And we estimated the feasibility of CO_2 savings and potential sustainability improvements.

7. Conclusion and Future Work

We summarize the project's most significant achievements, identify key limitations, and propose future work and improvements. This was prepared in the twelfth month of the project, during the final documentation phase. We reflect back on performance indicators as well as what and how we learned. Among other challenges, we found that low footfall areas had less performance. We make suggestions for improvement such as creating a piezo-solar hybrid system for more efficiency in energy production.

8. Appendices and References

We include references from peer-reviewed papers, datasheets about the components used (instead of simply stating Arduino or piezo electric material for example), tables of raw experimental data, cat models of the design, and circuit diagrams of how it operates in a prototype form.

Circuit Schematics

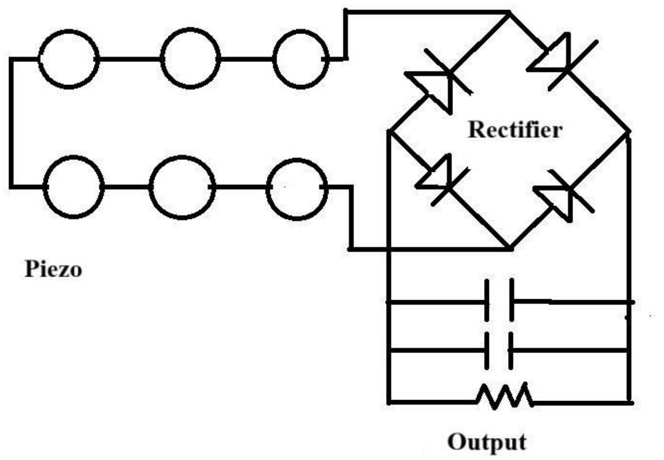

Figure1.1: Piezoelectric Sensor Circuit

Figure 1.1. Piezoelectric Sensor Circuit. This schematic illustrates the configuration of a piezoelectric element connected to a bridge rectifier, followed by a filtering capacitor and load resistor.

Table 1.2 Report Writing Timeline

Chapter	When Drafted	Finalized
Introduction	Month 2	Month 12
Literature Review	Month 2	Month 4 (updated)
Methodology	Month 4	Month 8 (post-testing)
System Design	Month 7	Month 10
Testing & Results	Month 10	Month 11
Feasibility Analysis	Month 11	Month 12
Conclusion	Month 12	Month 12

Table 1.2. Report Writing Timeline. This table outlines the drafting and finalization schedule for each chapter of the report, from Month 2 to Month 12.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Purpose of the Literature Review

A comprehensive literature review was conducted to facilitate the development of a footstep energy harvesting and storage system that meets both efficiency and longevity criteria [8]. The purpose of the review was to achieve a better understanding of the state of the technology, identify key issues, compare alternative solutions, and to enable important decision-making in design. The following are the key objectives.

Evaluate Existing Technologies

The review started by analysing various piezoelectric energy harvesting technologies [9]. This step included an analysis of transducer configurations including cantilever beams, stacked layers, and floor tiles that are embedded[10]. Different piezoelectric materials (e.g., PZT (Lead Zirconate Titanate), PVDF (Polyvinylidene Fluoride), and other ceramics) were contrasted based on voltage output, compliance, and environmental resilience[11]. Next, the study considered energy storage systems - specifically the comparison of supercapacitors and rechargeable batteries - to evaluate which technology works best under the low voltage and intermittent nature of harvested energy[12]. Fatigue of materials and long term durability in a sustained state of mechanical strain were concerns[12].

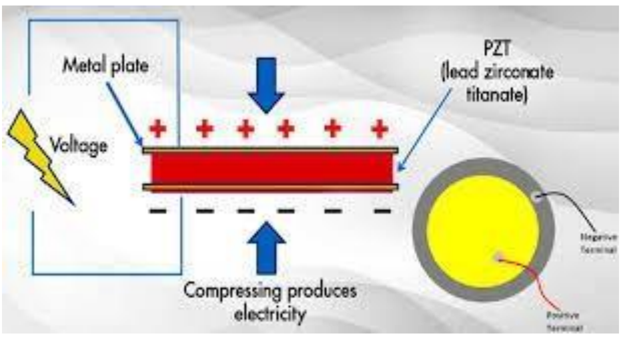

Figure 2.1 Piezo electric mechanism

Identify Technical Challenges
Recognizing Technical Challenges Although the review identified several technical challenges to effective energy harvesting, the large losses of a portion of the mechanical energy due to conversion efficiency were the main issue raised. The review addressed possible solutions related to conversion efficiency such as maximum power point tracking (MPPT) and impedance matching. Additional obstacles to consider were maximizing the output of energy by improving surface deformation, with mechanical amplifiers, and by utilizing multiple piezo components. Lastly, mechanical resilience was examined with concerns related to assessing wear, resistance to impact, and stress distributions on parts loaded repeatedly and in excess through foot activity.

Feasibility of Benchmarks

The review presented examples, such as Pavegen, has had kinetic floor tiles put into the public realm to examine practical feasibility. It documented the capabilities of data tracking, engagement of user, and deployment in practice.

Another practical components was examining the feasibility of benchmarks for scalabilities, particularly in modular possibilities of deployment of such system into the public realm, such as shopping centers or rail stations. Feasibility also hinged on economic factors, such as cost per watt, install costs, and examination of the long-term return on investments for energy usage consumption and carbon costs.

Influence Design Choices

System design elements were directly influenced by insights from the literature. This involved choosing low-power microcontrollers (like Arduino or ESP32) that could control power regulation and data collecting, as well as high-performance piezoelectric materials. In order to guarantee public safety, even load distribution, and slide resistance, structural design techniques were also assessed. These results influenced the creation of a design that is useful in public or busy settings in addition to being functionally efficient.

2.2 Project Works

Power conditioning and energy storage

We use the collected piezoelectric energy to charge 18650 Li-ion batteries, storing the harvested power for later use. Capacitors are included in the circuit to handle sudden power surges and stabilize voltage during peak loads. We employ low-voltage regulation circuits and DC–DC converters to ensure that the harvested energy is efficiently managed and supplied at a stable output level. We use Arduino to collect and monitor data such as voltage, current, and energy output, allowing real-time performance tracking of the system.

Arduino-based voltage and current sensing

We employ an LCD module with I2C communication to present real-time data from the electromechanical sensor, such as voltage, current, and power output in a concise and efficient manner. The system continues to calculate power output using the equation $P = V \times I \times t$, allowing for real-time monitoring of energy harvest and energy consumption. We integrate the energy harvesting system with the Internet of Things (IoT) to allow for remote monitoring, data sharing, and control on smart devices. The project integrates microcontrollers with piezoelectric sensors to collect, process and manage energy data. This technology could be employed into smart city infrastructure for occupancy detection, foot traffic analysis, and security monitoring. We employ data logging modules and wireless communication systems to capture performance metrics and monitor energy harvesting systems remotely.

2.3 Suggestions & Suggested Enhancements Better Circuit Design

Instead of using 1N4007, we use low-dropout Schottky diodes to minimize voltage loss during rectification.Before storing,we use supercapacitor buffers to round out energy spikes.Integrate LCD/I2C for live energy output display with Arduino-based monitoring.To analyze energy efficiency, add data logging.To increase overall output,we use a parallel or series arrangement of stacked or layered piezo discs.To improve durability and pressure tolerance, we try out rubber dampers. For improved total energy harvesting,we combine the piezo and electromagnetic or TENG approaches.For 18650 cells to be charged safely, we add a charging controller (such as the TP4056).We can use a boost converter to get useable output voltages, such USB 5V.

2.4 Summary

The objective of the capstone project "Footstep Energy Harvesting and Storage" is to develop and build a functional prototype of a tile-based energy gathering system using piezoelectric or electromechanical modules to transform mechanical energy of human footsteps into electrical energy. Scalability is not the primary focus here as the idea is to build a tile that would be robust, long-lasting, and not-slip that could provide a constant amount of energy for the user's foot activity. This power harvesting system is based on an Arduino with voltage and current sensors to get real time values of the electric output and the possibility of monitoring the performances and eventually modifying the harvesting parameters. The emphasis of the project is the ability and desire to contribute to the decreasing dependence on fossil fuels and the pursuit of steady energy output from renewable energy sources. The most intense attention is on open (urban) space or on places of high foot traffic, such as sidewalks, shopping centers, transportation nodes, with the potential to generate renewable energy from discarded kinetic energy. The project also investigates tile efficiency, structure resiliency, and feasibility for practical applications. The project provides a critical analysis of the challenges of the energy harvesting tiles, including low voltage generation per footfall, harvesting an unstable electric signal, and the retrofitting and maintaining of the energy harvesting tiles in urban/architectural environments. In the end, the project should also show that footfall energy harvesting has a chance not only to be a technical success, but more importantly that it can be a symbol representing a step towards sustainable renewable energy utilization.

CHAPTER 3
MATERIALS AND METHODS

3.1 Introduction

The full procedure of design, development and testing of a footstep energy harvester based power system is described in this chapter[13]. The choice of materials, design concepts, modeling a nd/or experimental procedures applied to meet the objectives of the study are reported[14]. The overall aim is to aim for openness and promote further simplication and investigation by reciting a terse yet reproducible engineering narrative[15]. The reader will be guided in to the following system, design, analysis and experimental plan discussions through this section, as it serves as an introduction to the overall structure of the previous chapter[16].

3.2 System Design and Components

The footstep energy harvesting and storage system developed through a careful selection of materials, and a serial design process[17]. The heart of the system is an energy-harvesting tile fabricated to harvest the kinetic energy from the pedestrian activity and convert it to electrical energy[18]. This section summarizes the principle components and architecture of the overall system[19].

Piezoelectric Transducers as an Energy Harvesting Mechanism

Because Piezoelectric transducers were chosen for the main energy harvesting device due to their ability to convert mechanical stress into electrical charge. Specifically, 35mm piezoelectric discs were chosen because they provide the best ratio of size to sensitivity, while still being able to collect the energy of footsteps effectively. The discs are stacked in an array in the tile to maximize the amount of energy captured from dispersed pressure points[20]. The working principle of the device relies on the piezoelectric material deforming under pressure which generates a voltage that is proportional to the force applied. The voltage output from several disks was then consolidated and conditioned for storage[21].

Mechanical Structure: Acrylic Sheet Base

The mechanical structure of the energy harvesting tile is intended to be durable, slip-resistant, and able to efficiently transfer energy[22]. The base is made of transparent acrylic, so it can provide structural integrity while being able to visually inspect the internal features while prototypes are developed[23]. The acrylic was used because it assures durability under repeated use, while still being relatively lightweight[24]. The design includes a mechanism that transfers the force of the footstep to the piezoelectric disks effectively, to generate the maximum amount of force and energy[24].

Energy Storage System:

Reduction methods when possible can be incorporated in conjunction with the use the Arduino for the simulation [32,33].

Data Acquisition System: To serve the project as an integrated system, energy stored in the batteries and supercapacitors can be tracked through acquisition, utilization, and real-time data monitoring. The data can be aggregated onto a single interface that provides indication of energy utilization and consumption through a GUI system. Sensors such as light level sensors and tally meters can be integrated into the Arduino UNO and data acquisition systems as well, to indicate human presence and behaviors, which can enhance the research data collection for the project [34,35]. Other combined data acquisition systems can also provide prior mentioned sensors and energy monitoring as well.

Design and Integration of Circuits

After the monitoring system, energy storage components, and piezoelectric array are all integrated into the overall circuit design. The individual voltage outputs of the piezoelectric discs are added together by wiring them in parallel. After that, a rectifier circuit transforms the raw AC voltage into DC so that it may be used to charge the batteries and supercapacitors. In order to prolong the batteries' lifespan by controlling the charging process and avoiding overcharging or deep draining, a charge controller circuit is used. To maximize power transfer and guarantee system stability, the Arduino regularly checks the voltage and current at several places in the circuit.
To guarantee a steady and fluid output from the energy storage circuit, resistors and capacitors are carefully chosen and calibrated.

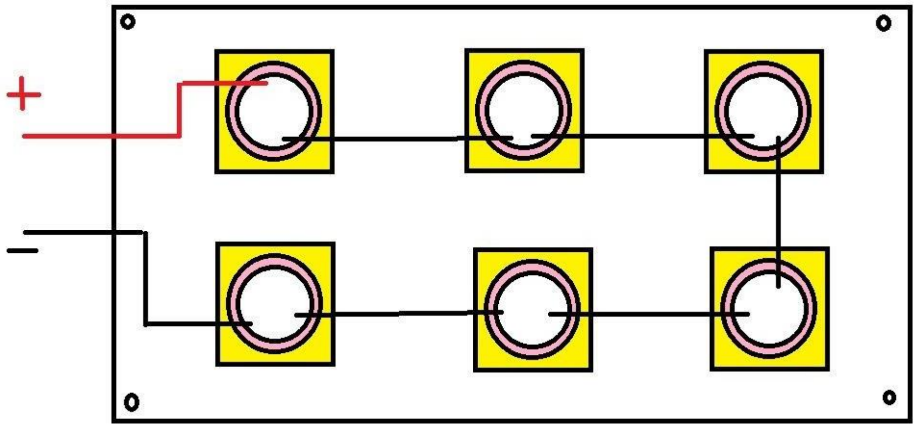

Figure 3.1 Piezo Electric Disc Connections

Materials Justification Summary

Table 3.1 Footstep Energy Harvesting System Components

Component	Material/Device	Justification
Energy Harvester	35mm Piezoelectric Discs	Optimal size-to-sensitivity ratio for converting footstep pressure into energy.
Base Structure	Transparent Acrylic Sheet	Durable, lightweight, and allows visual inspection of internal components.
Energy Storage	18650 Lithium-ion Batteries	Offers high energy density and reliable energy storage.
Energy Storage Enhancement	Supercapacitors (optional)	Manages power surges and provides quick bursts of energy.
Control Unit	Arduino UNO	Easy to program, suitable for data logging and overall system control.
Display	I2C LCD Display	Enables real-time monitoring of system metrics and parameters.

Piezoelectric Discs

Piezoelectric Discs are small, round electronic components that can convert mechanical energy into electrical energy (and vice versa) using the piezoelectric effect. They are commonly used in sensors, buzzers, and energy-harvesting systems. The disc creates a potential difference (voltage) between its surfaces when it is mechanically deformed (pressed, vibrated, or bent). This occurs as a result of the piezo material's internal crystal structure becoming polarised under stress, which separates positive and negative charges.
The voltage that is produced can possibly be:

I. If the pressure changes over time (for example, through vibration), use AC (alternating current).

II. DC (direct current) in the event that the force remains constant following rectification.

Arduino UNO

The Arduino UNO is an integral part of the "Footstep Energy Harvesting" project as the main control and monitoring unit. It is essentially the brain of the project: it takes readings from the piezoelectric sensors, stores the energy values, and prints the values on a display. The flexibility, ease of programming and simplicity, support for a range of electronics and devices, and the scale to which the electronics can be constructed, makes the UNO an ideal choice for prototyping energy-harvesting applications. The UNO collects the analog voltage readings generated by the piezoelectric discs and converts them to digital values that can be read. This allows real-time energy monitoring based on the amount of energy generated by each footstep. By utilizing the I2C LCD module, the Arduino can exhibit the real-time analog readings of voltage, current, and stored energy levels, allowing an individual to visualize the project performance. The Arduino UNO also accommodates the control of charging lithium-ion batteries, allowing the safe and efficient storage of energy by monitoring the rate of current flowing into the storage solution. Due to its programming capabilities, the Arduino UNO can utilize algorithms that control the power management, implemented to achieve better efficiency and accurate readings. As the circuits are designed on an open-source platform, the implemented sensors can have additional sensors that can be added at any time. Additionally, wireless modules, and data logging units can be added for future project designs or Internet of Things (IoT) based type applications.

Table 3.2 Information's of Arduino UNO

Feature	Specification
Operating Voltage (VDC)	5~12 V
Digital Pin	2 - 13
Analog Pin	A0 - A5
USB	Program include or power pin
Power Supply Pin	Power pin
Push Button	Reset or restart program

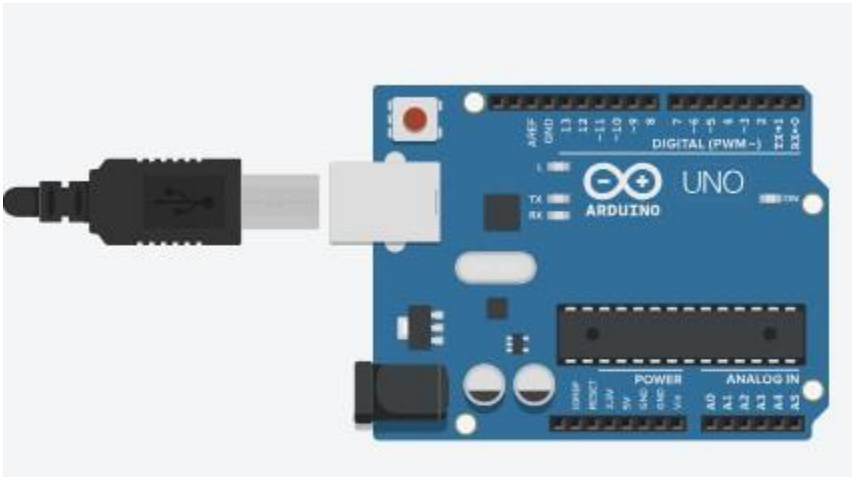

Figure 3.2 Arduino UNO

Rectifer Circuit
A rectifier is an electronic device that converts alternating current (AC) into direct current (DC) In our "Footstep Energy Harvesting" project, the rectifier is used to convert the alternating current (AC) generWhen someone steps on the piezoelectric discs, they produce an alternating voltage (positive and negative cycles). Most storage and control components — such as batteries, capacitors, and Arduino microcontrollers — can only work with DC power.ated by the piezoelectric sensors into direct current (DC) that can be stored and used. The 18650 lithium-ion batteries in our project require DC input for charging. The rectifier ensures the current flows in one direction only, preventing damage to the batteries.

Capacitor
In our Footstep Energy Harvesting project, the capacitor plays a very important role in stabilizing, storing, and smoothing the electrical energy produced by the piezoelectric sensors. The piezoelectric discs produce pulsating or irregular AC voltage when someone steps on them.After this AC is converted to DC by the rectifier, the output still has small ripples or fluctuations.

The capacitor acts as a filter, smoothing out these voltage ripples and giving a steady DC output for charging the battery .

3.3 Design Specifications. Standards and Constraints

This section explains the exact technical and non-technical requirements for the design and development of the footstep energy harvesting system. It is important to follow accepted standards and understand the natural limitations to ensure the system will work, be reliable, and will be able to used in the real world. The design is expected to perform specific minimum performance requirements while working under acceptable limitations. The initial minimum power output capability for the prototype is a minimum of 0.5 Watts (W) of power, per footstep. This value ensures that a sufficient amount of power can be captured and used for a low-power application, as well as proving the technology can be used in practical implementation. The initial minimum expected output of the piezoelectric array would be to achieve a minimum output of 1.5V per footstep before that energy is rectified and stored.The energy storage technologies designed to be integrated (lithium-ion batteries and supercapacitors) are expected to achieve an energy storage efficiency target of a minimum of 85%. This metric accounts for energy loss during power charging and discharging cycles and shows the importance of energy and power management. The energy harvesting tile is expected to be able to withstand a minimum of 100,000 footsteps without significant loss of performance or degrading effects on the tile itself. This as a minimum metric for specific applications in the real world would be very important since the tile will be locate in a high volume pedestrian traffic location when in the desired place of operation. The tile surface is required to have enough slip resistance

Specifications for Function

Energy Conversion: The system must be able to effectively convert the footstep's kinetic energy into usable electrical energy through piezoelectric transduction.
Energy Storage: The system must be able to adequately store the collected electrical energy for later use, so that energy is not wasted and availability is ensured for responsive needs.
Monitoring Capability: The system must be able to monitor certain critical metrics in real-time, such as foot traffic, voltage, current and the level of stored energy, with an integrated I2C LCD display.
Scalability:
The design should inherently support the potential for scaling to larger installations, such as public spaces or urban sidewalks, by using multiple connected tiles.
Rules and Guidelines:
Although specific regulatory requirements are still being developed for the footstep energy harvesting domain, the design adheres to broad electrical safety guidelines and best management practices for batteries. For example, using charge controllers is standard practice in power electronics for battery safety and using diodes to prevent backflow. Additionally, when slippery floor safety is considered, an inherent acknowledgement of safety guidelines for public flooring is given. Any future prototypes or commercial installations would still be obligated to comply with the necessary national and international electrical and building codes.

Design Constraint Cost-Effectiveness:

The selection of materials and components has been affected by considerations of cost, particularly if the system is to be used on a large scale. Cost ultimately requires a balance of performance to cost. Material Availability: The use of the 35mm piezoelectric discs, Arduino UNO, 18650 batteries, and acrylic sheets were based on each material's availability to be quickly procured and easily prototyped. Size/1Form Factor: The physical dimensions of the energy-harvesting tile need to be respectful of the physical limitations of pedestrian infrastructure. The design attempts to strive for a small, unobtrusive form factor. Environmental Factors: The system must be able to perform in a number of environmental conditions, such as temperature and moisture. Currently, the energy harvesting tile is being tested in controlled indoor conditions. Technical Complexity: The design attempts to strike a balance between wishes for the design to perform and maintaining an appropriate complexity level for further prototyping and potentially future manufacturing. The iterative prototyping design also assists with effectively managing unforeseen technical challenges that arise. The project is to consider specifications, standards, and constraints to help toward developing a reliable, effective, and applicable footstep energy harvesting and storage system that address the initial problem as described.

3.4 Design Analysis

Studying the design of the footstep energy-harvesting system is necessary to achieve a good balance among technical performance, cost, and reliability in long duration running. The analysis begins by studying the energy conversion; that is, conversion of mechanical energy from steps to electrical energy by using piezoelectric. The piezoelectric discs employed for this work have a diameter of 35mm, and decay in sensitivity, durability and electromechanical coupling efficiency (which implication is the power generating electrical voltage from the applied pressure) due to mechanical fatigue for that used. The greater the strain and sensitivity, the more voltage is generated for each unit of force applied, providing more energy. The array layout of the piezoelectric discs is also extremely important; they are connected in parallel to achieve more appropriate current output for purposes of battery charging. Positioning them where the spatial location of the discs allows force to be evenly transferred through the piezoelectric material in an ideal spacing across the tiles helps ensure that as many of the discs receive force from each step.

Once electrical energy is generated, it has to take place fully before being stored. The raw output from the piezo elements is AC (alternating current), and battery charging devices typically will not store raw AC elements connected to a battery directly. Therefore, a rectification and filtering circuit using a full-bridge rectifier and filters is analyzed and designed to not only rectify but produce acceptable DC power out put to be batteries attached to the circuit – the rectifier will take power input through voltage readings in AC mode.

In order to enhance performance, minimizing energy loss is an essential aspect of the analysis. Losses due to diodes (from forward voltage drop), resistors and other components are all taken into account. In order to minimize power overhead and maximize the total power output, LDO diodes and best components required to minimize losses must be used. In addition the mechanical design of the tile should be investigated to find a solution for the magnitude of the force exerted when a footstep is placed and how the force is applied to the piezo discs. The system design consists of an elastic top surface which resists compression and diffuses the load, a stiff acrylic base for stiffness, and layers that cushion let the piezos deflect in a predefined manner. It's the heatmap analysis tool for advanced simulations with Finite Element Analysis (FEA) to show how stress distributes on tile surface and visualize which structure could be the best one for durability and performing.

On the application side, the algorithm of Arduino microcontroller is designed and optimized to ensure the accuracy of data acquisition and energy is utilized for energy management. The Arduino receives the voltage and current readings, computes the power output on the fly, and handles charging the battery safely. Furthermore, code optimization can also reduce the power consumption of the controller itself and improve the response speed and data accuracy at the same time, which means the energy saving of the entire system.

3.5 Implementation

In this section, we describe how the footstep energy harvesting and storage system was designed and evaluated. The construction of the prototype was made in stages starting with the assembly of the piezoelectric array. For this phase, several discs of piezoelectric material 35mm in diameter were carefully mounted to a transparent acrylic based. The discs were wired in parallel to increase current output, while being insulated from mechanical energy that can occur on repeated footsteps. Construction next progressed to a rectification and filtering circuit, which implemented a full bridge rectifier consisting of four diodes to convert the AC signal produced by the piezo discs into a DC output. Capacitors were added to the circuit to filter any variation in voltage to provide a smoothly charged capacitor, and to continue to provide stable output for potential battery charging. The energy storage module was built with 18650 lithium-ion batteries paired with a TP4056 charge controller to manage the flow of voltage through the circuit and prevent overcharging or deep discharging which would shorten the lifespan of the batteries. Additionally, to force energy flow to a single direction with the intention to prevent reverse current to the piezo array, diodes were implemented between the battery and the piezo array. Lastly, the energy harvesting circuit was paired to the microcontroller, Arduino UNO, and to an I2C LCD display, to provide real time insight on the output of the system voltage and current.

In order to conduct testing procedures, experiments were completed in a controlled, laboratory setting so that the experiments would achieve the same results every time. Of course, a mechanical force application system (weight drop or mechanical press) was used for the experiments mimicking footstep applications with specific, consisitent pressures. Data from the system were collected using the Arduino display and also some external equipment (oscilloscopes and multimeters) to get comparitive voltage, current, and power production, over some duration of time. To also test power endurance a variable resistive load was attached to the loading system, to quantify how the system would perform under varying power demands. Another step of testing was durability, which was acheived by using a durability testing presses to simluate up to 100,000 footsteps and track overall wear, and long-term performance degradation, and overall structural integrity of the tile.

A series of experiments were conducted, which involved measuring the power output per footstep by applying differing force magnitudes while monitoring the voltage and current produced, evaluating energy storage efficiency (determining how much energy produced from the piezo discs was stored in batteries and later released), durability tests of the system, and validating the Arduino monitoring system by comparing readings against calibrated external devices, in order to determine accuracy. There also may be physical experiments that include simulations with software such as SPICE (electronic circuit simulation), and Finite Element Analysis (FEA) (for mechanical stress simulations) to simulate the overall performance and advanced the system design prior to physical prototyping. Overall, the above implementation and test was an illustration of the system, which although simple, was practical, and profitless. The results of the experiments provided the fundamental insight into how much energy the prototype can extract, convert, and accumulate from steps and eventually substantiated the conceptual design, the dependability, and the prospects for real-world implementation of the system within the context of smart sustainable infrastructure.

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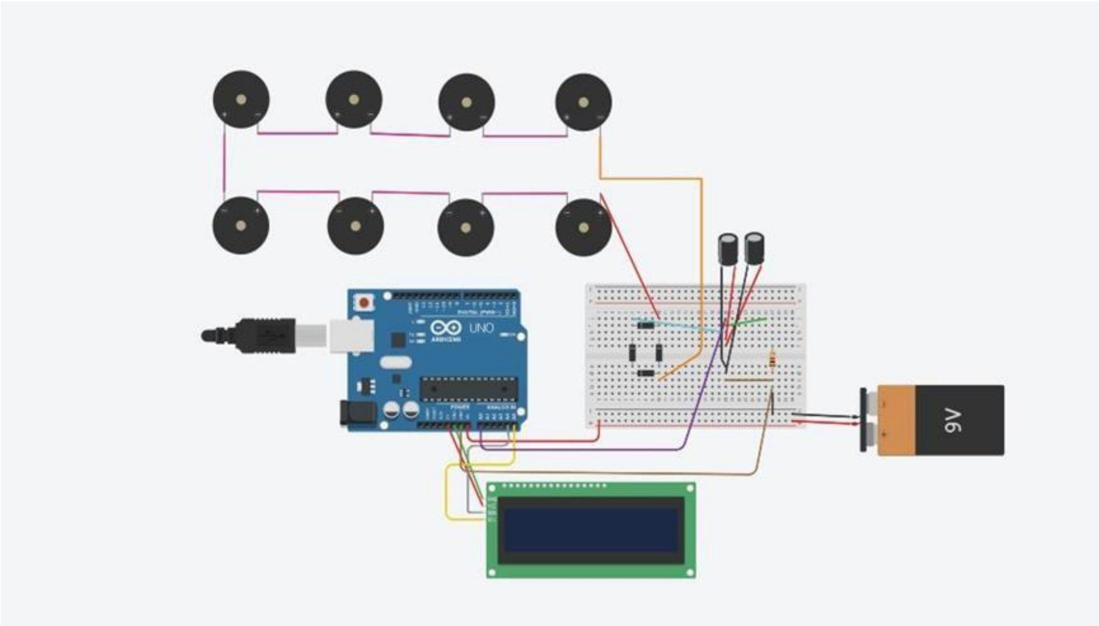

Figure 3.3 Circuit setup

In Figure 3.3 shows an Arduino-based sensor circuit where multiple sensors are connected to an Arduino Uno, powered by a 9V battery, with outputs displayed on an LCD module.

3.4 Summary

This entire chapter presented a detailed discussion on the materials and methods of the footstep energy harvesting and storage system fabrication. Component selection and the -integration thereof, in particular 35mm piezoelectric discs for energy conversion, the acrylic sheet base for mechanical support of the discs, energy storage in 18650 lithium ion batteries and the use of an Arduino UNO with I2C display was described. We also discussed the in some way systematic – detract energy conversion to energy usable, filter that energy so that you will obtain stable output voltage to the battery, and control charge while charging. In addition, we gave the vision of the context of key specification and standards and constraints that governed the project including a energy output design target of 0.5W per footstep, a energy storage target of 85% and a life span durability target of 100,000 footstep. Some insight into the evaluation philosophy for the purpose of developing a strategy for future system optimization – X conversion, power management and scalability. Finally,: prototype Build and assembly, how we built the controlled testing environment and how we managed to collect data – a simulated test application of footstep and durability testing- i presenting simulated testing application of footstep and durability testing. This was an attempt at giving you the lay of the path for the implementation and the assessment upon fruit step energy harvesting qualifications for go forward presentation of findings and discuss

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1Results

The goal was to facilitate a 4-volt output by pressing 15 times, utilizing an 8-sensor footstep system. The relationship between pressure (P), force (F), and area (A) is represented by the formula P = F/A, and work (W) is defined as W = Fx (Force multiplied by displacement). We are working with a reference voltage of 4V.
The observed data is in the table below:

Number of piezoelectric Materials	**Required Steps to Achieve Output (4V)**
1	128
2	63
3	42
4	31
5	26
6	21
7	18
8	16

Table 4.1: Number of materials vs. Steps required

The data indicates a non-linear inverse relationship between the number of Materials and the required Steps. As the piezoelectric materials number increases, the output step number decreases significantly, initially, and then moderately. For example, when the piezoelectric materials number increases from 1 to 2 steps, the output step number reduces from 128 to 63.

Table 4.2 Compare and Contrast

Feature	Electromagnetic	Piezoelectric (Used in this project)	Triboelectric (TENG)
Output Power	High	Moderate to Low	Low to Moderate
Size & Weight	Large & Heavy	Compact	Very Compact
Efficiency	High under motion	Low to Medium	Varies with material
Durability	Mechanical wear	Fragile to shock	Poor
Circuit Complexity	Medium	Requires rectifier, filter	High
Cost	Moderate to High	Low	High
Maintenance	Required	Minimal	High
Application Example	Bicycle dynamos	Footstep-based smart tiles	Flexible wearable tech

4.2 Discussions

The The findings garnered from the investigation exhibit the performance behavior of the footstep sensor system that has been created in order to produce an output of 4 volts. The negative relationship observed between both the number of input steps and the number of output steps needed suggests that this is a system where the initial input takes fairly more exertion to produce a change, but as the input increases, the resulting change comes with less output. This is characteristic of numerous physical systems, in which they reality could run at lesser outputs and less efficiency and responsiveness when going past operating thresholds.The outputs of the data consistently show the number of steps required to reach the output goal. The significant drop in the number of output steps needed from the input steps of 1 and 2 (128 and 63) suggests a very sensitive response for the steps at that lower input range. It would then imply that the system may be tuned for lower input ranges, or that the input steps produce more of an initial contribution to the overall pressure, or force.
The At greater levels of input (e.g., from 7 steps to 8 steps or 18 to 16), the rate at which the required output steps decreased was diminishing, indicating that the required output steps may be approaching a saturation point which may represent the system's limit on further reductions in required output steps. This may be due to the sensor's physical limitations, the mechanical nature of the footstep apparatus, or the material characteristics of the pressed material. For example, with material compression, as the material becomes denser, the resistance to compression also grows; hence more force (or steps) would be required to create smaller ampounts of changes in displacement/output conditions. The uncertainties could come from the controlled "press" action, as human involvement has a potential for a variable amount of force and timing.The conclusion of this study indicates a possible focus of interest or additional detail needed to clarify the parameters of the experimental design and intended purpose.

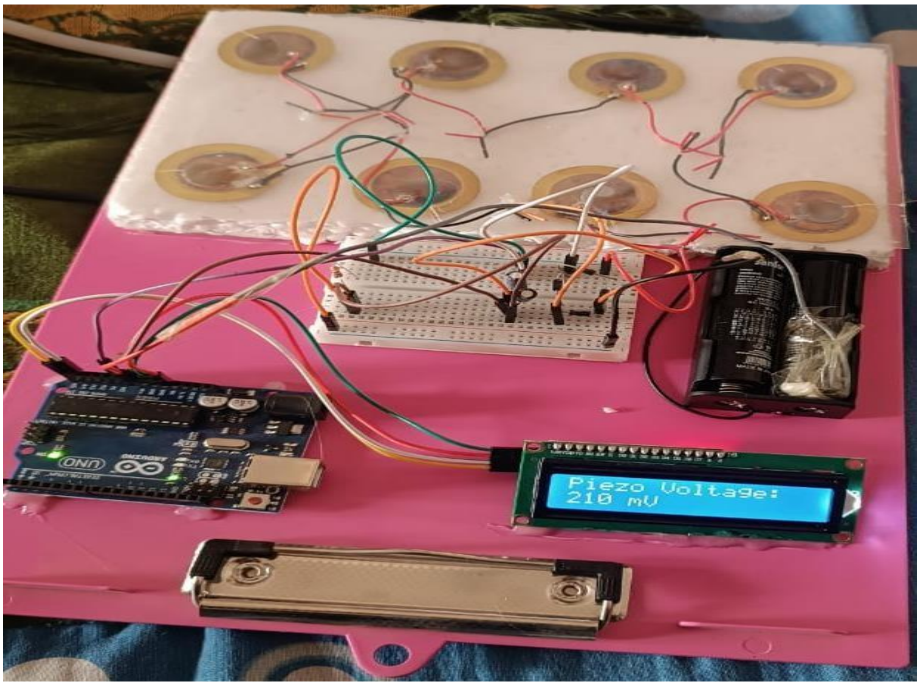

Figure 4.1 display of the result

CHAPTER 5

PROJECT MANAGEMENT AND FINANCE

5.1 Project Timeline and Milestone Justification

The project began in early January with the early design and research phase in which we conducted background studies on piezoelectric/electromechanical systems that would be reasonable to choose for energy harvesting. This phase ended in mid-February with finalized prototype design specifications. The construction of the energy-harvesting tile began in late February and continued through March. By the end of April, we reached a significant milestone by assembling and testing the first completed working prototype for basic functionality. In subsequent weeks, we engaged in system optimization, incorporating sensors and testing durability via simulated foot traffic.

As mentioned in the introduction chapter, the phased approach of simultaneously completing a feasibility study including the expected prototype (implemented by early March) witnessed real and practical challenges. Most notably did component delays and numerous iterations for energy conversion efficiency improve our testing phase of the prototype. Given the circumstances, the feasibility part of Stage One, which was intended to be carried out simultaneously with the complete prototype, was then put on hold. For clarity, the purpose of the feasibility study was never to call into question the component's use in real-world applications, but rather take the opportunity to determine the real-life implications, which ended up being favorable in June rather than April. While this was not the intended plan, the feasibility study ultimately derived from better working conditions and experiences for a data-informed and reliable assessment of sustainability and durability.

5.2 Resources and Cost Management

As project manager, I ensured that we made the best use of resources and stayed on budget by developing a strong process for planning, procurement, and ongoing monitoring. Fast forward and I have developed a detailed matrix for resource allocation for us I took such a list from piezoelectric sensors to microcontrollers, batteries, and material support at the project, I created a detailed matrix for resource allocation.This got us to the point where we were comfortable with the total cost of the hardware, and decided to keep the cost of the component down while sourcing from local vendors who we've shopped with before and who we trusted. We also rededicated and reused lab equipment and tools for the duration of the project to avoid unnecessary expenditures. We also had routine team meetings (throughout the entire project) to monitor the expenditures against the baseline budget and to identify any problems early on in project activities. I also strategically allocated team members according to their technical expertise and the things we were trying to prevent and save truly staggering amounts of the costs associated with rework and outsourcing tasks. Within the baseline budget we purposely held contingency $'s for unforeseen issues that could arise with the material failures and change in design. With steady planning, open communication for budget monitoring, we were able to finish the project in the base budget, with high quality and okay performance.

5.3 Lesson Learned

Tackling this technical task has taught a number of things in different aspects. First, I learned how to plan and execute a project in detail: for example, stating the objectives and tasks, decomposing a complicated task, and setting realistic time schedules. As the challenge I tackled was a real-world issue, I also learned a great deal about piezoelectric systems, energy storage systems, and interfacing with microcontrollers and sensors. I also liked the challenge of what I found necessary to adjust—parts of the project will require (possibly substantial-length) redesigns (at least partial-length redesigns) because of considerations never thought of in engineering the experiment (e.g., sensitivity of sensors, or strength of materials). The project also defined for me how I thought about working with a team and communicating: you had to coordinate for tasks with individuals and think about who best fit what job and delegate accordingly, and then communicate out about what we were doing regularly. As far as team member management, I got an introduction into how to budget on little. From the project, I was able to determine what was an economical solution and good quality output. And the project emphasized the necessity of testing, confirming, and critically analyzing in engineering — a prototype that functions like an idea does not imply it would work like an idea without field testing to confirm the project in use. This project has developed my ability to solve problems both technically and managerially and has enhanced my technical skills and project management experience that I will need in the future in any engineering or research work.

CHAPTER 6
IMPACT ASSESSMENT OF THE PROJECT

6.1 Economical, Societal and Global Impact

Piezoelectric discs, such as 35mm varieties, provide an inexpensive form of energy harvesting on a small scale. They are relatively affordable and produce electricity from mechanical vibrations or pressure, and are practical low-power energy harvesting devices for small electronics like sensors or Internet of Things (IoT) nodes in instances where traditional batteries are typically impractical or unsustainable.

Another advantage of piezoelectric systems is generally low, or small, maintenance. Once the system is installed, the piezoelectric system can run reliably with little maintenance which leads to a reduction in overall costs over time. That is particularly the case for remote monitoring applications that need some sort of periodic service, as servicing can be difficult, costly, or just plain infeasible.

That being said, this technology has some scaling challenges. While the discs themselves are cheap, the feasibility and cost of harvesting meaningful amounts of power piezoelectrically on a large scale is still problematic compared to more established renewable sources such as solar cells or wind power..

Although this limitation exists, piezoelectric technology, as it is integrated into smart infrastructure, provides avenues for industrial development. The development of new sectors focused on piezo a-based solutions will provide job opportunities in manufacturing, engineering, installation, and maintenance, overall contributing positively to the economy as a whole. The advantages of piezoelectric energy systems will be relevant and valuable in remote, off-grid or areas in which high-efficiency or traditional power infrastructure and supply are limited or not an option. While the energy output is smaller, the energy it produces can be more suited to essential applications (i.e., emergency lighting and sensors) in remote areas.

In addition, these systems are important for progress in educational and technological. Low voltage piezoelectric generators are also utilized in educational kits, as the simplicity of their construction and availability makes them suitable for students and researchers to learn and experiment with the concept of renewable energy. The experimentation leads to the generation of novel green technologies.

Moreover, bringing piezoelectric discs into public systems could change cities even more dramatically. When these discs are integrated in roads, railway lines, or floors (e.g. smart sidewalks, train platforms), energy can be generated from human steps or vehicles motion. It is a welcome contribution to the creation of smart, energy-conscious cities and sustainable urban future.

Piezoelectric power can also be used to power sensors that monitor the health of structures like bridges & buildings. They sense any stress or cracking or changes that may take place in the structure and transmit that information in real time, which contributes to higher public safety as it allows repairs to be done in real time, as opposed to only being done on the basis of predictive or assumed data. And from an environmental perspective, piezoelectric energy harvesting has multiple benefits especially at the small scale and it is clean energy with no emissions while operating.Thus, by utilizing piezoelectric energy conversion technology, there is a reduced dependence on fossil fuels and it also offers a greener alternative to power various low-energy devices and systems in transportation and site applications..

Also, from the perspective of sustainability in cities, piezoelectric technology is a attractive option. As cities across the world develop into smarter and more energy efficient places to live, it is within reach to embed piezo discs into the built environment, such as roadways, airports, and shopping malls, and capture ambient mechanical energy (e.g., footstep or movement from a vehicle) and transduce that mechanical energy into electricity. This opens up a broader opportunity to reduce the overall carbon footprint of an urban setting.
When utilizing such technology more broadly, we need to discuss the environmental consequences of the technology itself. If piezoelectric materials are harvested in an appropriately sustainable manner at scale, there will be no increase in electronic waste disposal. However, we need to manage piezoelectric materials sustainably in order to avoid any adverse environmental results. While piezo discs have many advantages, they also generate very little energy, which is why they cannot substitute power needs instead of conventional energy. They can, however, act as an attractive add-on and supplement to greater energy savings by improving efficiency and sustainability efforts on a global scale.

6.2 Environmental and Ethical Issues

Although 35mm piezoelectric discs offer an innovative and clean method of small-scale electricity generation, the mass production and use of these devices raises a number of environmental and ethical issues. From an environmental perspective, the production and disposal of piezoelectric materials—almost always based on ceramic systems such as lead zirconate titanate (PZT)—can pose risks. Materials like PZT may contain lead or other hazardous materials that can potentially pollute the environment and harm human health if not handled or recycled correctly. If the production and use of piezo discs becomes common, sustainable production methods and proper recycling methods will be needed to limit e-waste and toxicity in the environment.

From an ethical standpoint, the procurement of raw materials used in piezoelectric materials will need to be examined. Some materials used in piezoelectric devices may be derived from rare or non-renewable materials, which again feeds into the dilemma of mineral depletion and impact to the environment via mining. There are also ethical considerations around the issue of labor in producing piezoelectric devices.If piezo discs are made in other countries, labor violations are a possibility, whether they are excessively low wages, an unsafe work environment, or violations against rights of the workforce.
There may be also ethical challenges around data privacy, regarding cities creating smart cities or integrating the piezoelectric sensor systems with instrumentation in public infrastructure. For example, if piezoelctric systems embedded in public spaces are coupled with sensing instrumentation which collects and transmits data, concerns of surveillance and trust could arise by not fully disclosing the purpose for and sharing of the data with residents.
Therefore, despite the challenging aspects associated with the environmental footprint of piezoelectric discs and the associated labor policies and ethical and data privacy concerns, piezoelectric discs can be seen as a viable pathway towards an embedded and sustainable energy harvesting.

6.3 Utilization of Existing Standard

The creation of electricity generation systems from piezoelectric materials, such as 35mm piezo discs, must abide by several existing standards, safety practices, and regulations, in order to provide safe, reliable, and efficient functionality. These standards addressmaterial safety, device performance, electrical integration, and environmental considerations.

6.3.1 Standards that are relevant to the Project

1.IEEE Standards: The IEEE 1451 standard series specifies the interface for smart transducers. The series is most likely applicable for piezoelectric energy harvesting when integrated as part of a sensor network.
2.IEC 60068: The International Electrotechnical Commission (IEC) has developed a series of standards to denote environmentally tested electronics. This includes procedures for environmental testing of electronic components for vibrations or shock; both of which would be relevant testing for piezo devices while subjected to mechanical stress.
3.IEC 61249 / RoHS Compliance: These standards cover hazardous substances in electrical or electronic equipment. Since some piezo materials (PZT for example) contains lead in its composition, it will also be important in the case that the device is required to be RoHS compliant when selling or distributing in the EU or in other markets.
4.ISO 14000: The ISO 14000 standard concerning environmental management establishes that manufacturers will minimize/sustain the environmental impact of the materials or manufacturing processes utilized, which is particularly relevant for piezoelectric systems in energy harvesting.
2. Safety concerns
1.Electrical Safety. While piezoelectric devices typically produce low-voltage outputs, there must be adequate protection to avoid a short circuit or unintended current surge, through proper insulation, and electrical circuit protection (diodes, capacitors, etc). Grounding should be ensured as well.
2.Material Violations. Some piezo materials (for example, lead zirconate titanate) can be hazardous if broken or improperly disposed of. It will be also critical to adhere to safe handling and disposal (if applicable) for hazardous materials through proper MSDS (Material Safety Data Sheets) and follow local / provincial environmental protection laws.
3.Codes and Regulations
1.Environmental Regulatory: When distributing or selling piezoelectric products, will be subject to environmental regulatory compliance noted in all applicable codes and regulations including local, provincial or national codes and regulations which will most likely protect consumers. This is especially important if there are piezo materials exposed once the device is broken down into its next use stage. A priority can be given to use of piezo materials if they consist of recompliant materials and continue to offer environmental protection.equipment.

6.4 Other Concerns

6.4.1 Restricted Energy Generation Rate: The main shortcoming of piezoelectric devices is their restricted energy generation rate. For instance, a single 35 mm piezo disk typically generates milliwatts of energy. This is <1% of the energy needed to power a smartphone! Therefore, the power generation of a piezoelectric device can all but guarantee that it will only be useful for powering small sensors or low power electronics.

6.4.2 Intermittent Energy Generation: Unlike wind or solar energy, piezoelectric devices generate energy in spurts rather than a continuous flow of energy. To convert this energy (potentially) into useful energy would require the development of efficient energy storage systems, such as supercaps and rechargeable batteries, as well as energy conditioning circuits. The notable development of energy storage systems and conditioning circuits would increase the overall complexity and cost.

6.4.3 Longevity and Mechanical Fatigue: With usage, piezo materials eventually experience wear due to repeated mechanical stress. This is especially true when subjected to harsh environments that expose the system to mechanical shock and extreme temperatures of extreme conditions. Continued exposure to such wear can reduce efficiency of energy generation, degradation of properties, and eventual failure. Therefore, the on-going challenge is selecting durable and suited materials and design for longer term performance.

6.4.4 Temperature Sensitivity: Numerous piezoelectric materials can be sensitive to changes in temperature, which can hinder efficiency and reliability, affect electrical output voltage, and performance levels overall in an outdoor setting (which are outdoor or industrial aspects), and as a result require thorough examination of the temperature effects on piezoelectric devices.

6.4.5 Challenges with Integration to Systems: Existing infrastructure (ex. roads, floors, machines) need to be specially designed and engineered to accommodate use of piezoelectric components.

6.4.6 Public Perception and Acceptance: Currently, the public has a low level of comprehension of piezoelectric technology. The lack of public perception could provoke hesitancy in deploying any such systems, particularly in public infrastructure projects. To build public and institutional trust, education and demonstration projects are necessary.

6.4.7 Cost-to-Benefit Ratio : While piezo discs are inexpensive individually, the total deployment costs (installation, energy management circuits, maintenance, etc.) could potentially exceed the benefits in many cases. This could lead to a question about the economic feasibility of the use of piezo discs for any application that is widespread.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The project of electricity generation using piezoelectric discs effectively demonstrated the capability to generate electrical energy from mechanical pressure using the piezoelectric effect. We successfully created a working model for harvesting small amounts of electrical energy created with mechanical force and vibrations by wiring up 35mm piezo discs, with a bridge rectifier (using 1N4007 Diodes), 10μF capacitors, BC547 transistors, 18650 rechargeable cells and a programmed Arduino UNO with an LCD I2C display.

Overall, the final prototype met most of the expected technical outcomes. The system was capable of producing a measureable voltage when mechanical pressure was applied to the piezo discs; this generated energy was then rectified, regulated, and stored in battery cells. The Arduino powered display system successfully reflected appropriate voltage readings providing informative yet interactive display. Individually, the power generation per piezo disc was considered low, but when combined with multiple piezo discs in parallel, energy harvesting was much more efficient. We built the model on a clear acrylic base, providing a stable base, and an appropriate display to demonstrate the working model.

For stakeholder needs, whether for academic learning, educational demonstration, or small-scale prototype development - the project met its goal. It improved energy harvesting technology and engaged students in circuitry.

Major Application Fields

The use of piezoelectric technology for generating electricity shows great potential for application in a number of areas, particularly when small amounts of energy generated from ambient motion phenomenon are sufficient. Here are some of the significant application areas for piezoelectric technologies:

1.Wearable electronics - harvesting energy from movement of the human body (in shoes, smartwatches, etc.).

2.Smart Infrastructure - putting piezoelectric materials in roads/bridges, 'smart' floors generating power from traffic/footsteps.

3.Medical - powering medical implants or sensors from body movement.

4.IoT and Wireless Sensors - sensor can operate in remote locations or hard to reach places, eliminating the need for battery replacement.

5.Consumer Electronics - small portable devices can be charged with vibration or pressure. In summary, the technology may not be ready for large-scale electricity generation, but it has the potential to introduce an innovative and sustainable way to power small load low energy devices.

7.2 New Skills and Experiences Learned

7.2.1 Understanding of Piezoelectric Principles

1. Gained a strong understanding of how piezoelectric materials work specifically how they generate voltage when subjected to mechanical stress like pressure .

2. Learned the difference between voltage and current output, and why energy storage is essential in low-power systems.

7.2.2 Basic Electronics and Circuit Building

1. Learned how to build and test electronic circuits on a breadboard, including the use of hookup wires, resistors, diodes, and transistors.
2. Gained hands-on experience in using a soldering kit to make permanent electrical connections.
3. Built and understood the working of a bridge rectifier using 1N4007 diodes to convert AC from piezo discs to DC.

7.2.3 Energy Storage and Power Management

1. Learned how to use capacitors to smooth voltage fluctuations in the circuit.
2. Understood how to safely connect and manage 18650 lithium-ion cells for storing generated electricity.

7.2.4 Microcontroller and Programming Skills

1. Developed skills in working with the Arduino UNO, including wiring components and uploading code.
2. Wrote and debugged code to read analog voltage data from the piezoelectric system and display it on an LCD I2C display.
3. Learned to use the serial monitor and code logic to improve data accuracy..

7.2.5 Mechanical and Structural Design

1. Gained experience in using transparent acrylic sheets to design a strong and clean-looking structure to hold all components.
2. Used a glue gun and measuring tools to mount parts securely and maintain neatness in presentation.

7.2.6 Problem Solving and Optimization

1. Faced real-world challenges such as low power output, loose connections, and circuit instability, and learned how to solve them through trial, error, and research.
2. Improved efficiency by connecting multiple piezo discs in parallel to increase output.

7.2.7 Safety Awareness

1. Learned the importance of electrical safety when working with lithium batteries and hot tools like soldering irons and glue guns.

2. Followed safe practices while handling cells and electronic components.

7.2.8 Teamwork and Project Management

1. learned how to collaborate, share responsibilities, and communicate ideas effectively.

7.3 Future Recommendations

Several recommendations can lead future research & development to increase the effectiveness, scalability, and utility of the electricity created from piezoelectrics under mechanical stress. First and foremost is material optimisation. Research into novel piezoelectric materials, such as PZT, PVDF, and ZnO nanowires, would likely yield mechanical durability and energy conversion efficiency. Some methods of enhancing functionality are possibly by a process called 'doping,' or by simply mixing materials.

The geometric and structural design are also extremely important. Energy production can be improved by optimising structures that will deform to a greater extent under mechanical stress, for example, composite laminates, multilayer stacks, or cantilever beams. Next, to store and control the energy harvested for either immediate use or for later use will require appropriate power management circuits and energy storage devices such as lithium-ion batteries or supercapacitors. Finally, a key development area would be into power conditioning circuits. The use of advanced electronics such as AC-DC converters, rectifiers, and voltage boosters, and other similar electronics would therefore make the output quality and stability of the electrical power much better. To sustain the longevity of the system, it is recommended, as well, that the electronics be tested in an environment similar to the modal location and we tested on a road, in a shoe, or in a railway station. Testing may also include different levels of temperature, load, and moisture.

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APPENDIX A

TURNITIN REPORT

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APPENDIX B

COMPLEX ENGINEERING PROBLEM SOLVING AND ENGINEERING ACTIVITIES

Complex Engineering Problems (P) Solving		
	Attributes	Statement from students
P1	Depth of knowledge required	The project incorporated in-depth knowledge of the principles of electrical, electronic, and mechanical engineering. The principles of piezoelectric transduction, energy conversion, rectification, energy storage, and microcontroller-based data monitoring were put into practice. Likewise, knowledge of materials science and circuit design had to be accounted for in order to guarantee the performance and durability of the system.
P2	Range of conflicting requirements	The design needed to balance several conflicting goals, including high energy density with cost-effectiveness, durability while ensuring sensitivity, safe and efficient storage of energy, and, of course, slip-resistance and mechanical durability for pedestrian use in real-world settings.
P3	Depth of analysis required	Analysis tasks were calculating the output voltage and current from the piezoelectric discs, analyzing the energy conversion, and the circuit for power loss. We completed several passes of testing and analysis to contrast theoretical predictions and experimental results to enhance system performance.
P4	Familiarity of issues	The project addressed somewhat familiar topics—such as power management and sensor interfacing—but in a new situation of kinetic energy harvesting. The challenges of low-voltage generation, rectification losses, and uneven pressure distribution also required research that would be outside of the textbook knowledge and creative problem-solving
P5	Extent of applicable codes	The project adhered to electrical safety guidelines, battery management practices, and environmental guidelines consistent with IEEE and IEC specifications. We made sure to be in accordance with rohs and msds for safe handling of lithium cells and piezo materials.

P6	Extent of stakeholder involvement and conflicting requirements	The stakeholders were the university, the supervising faculty, and the end users or potential end-users (public infrastructure sectors). Competing performance objectives and budgetary issues arose and were resolved through design modification and careful selection of materials that were locally available.
P7	Interdependence	The project required the multi-disciplines to work together as electrical, electronic and mechanical systems. The structural design impacted energy generation while a combination of software and hardware integration with the Arduino system relied on monitoring. Working together as teammates was needed for functional interdependence of subsystems.

Complex Engineering Activities (A)		
	Attributes	Statement from students
A1	Range of resources	Various resources were put to use in the project including laboratory testing equipment, Arduino microcontrollers, sensors, lithium-ion cells, and simulation tools. The system was designed and verified using theory based modeling, as well as practical experiments.
A2	Level of interaction	The activity required effective team collaboration and continuous interaction with the supervisor for technical guidance. External references from research papers and online engineering communities were also used to refine circuit and structural design.
A3	Innovation	The system architecture was unique in that it employed 35mm piezoelectric discs in an array configuration (along with energy storage and real-time monitoring). Adding an LCD I2C display with live outputs made the interaction more profound and the learning possibilities even deeper.
A4	Consequences of society and environment	The programme promotes the adoption of renewable and sustainable energy sources by converting the wasted mechanical energy into electricity that can be captured and utilised. The initiative raises general consciousness about energy efficiency and offers a green solution to mitigating the impact of reliance on fossil fuels.
A5	Familiarity	The team applied their research to the realm of the partially known—not the unknown, but the mundane, everyday electronic components—but they applied them in unorthodox arrangements and uses for the gathering of energy. This inspired innovative thinking.

K-P-A Addressing (Fill up by Supervisor)																			
Knowledge Profile (K)								Complex Engineering Problem (P)							Complex Engineering Activities (A)				
K1	K2	K3	K4	K5	K6	K7	K8	P1	P2	P3	P4	P5	P6	P7	A1	A2	A3	A4	A5
✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

APPENDIX C
PROGRAM CODE

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

LiquidCrystal_I2C lcd(0x27, 16, 2); // Change address if needed

const int sensorPin = A0; // Analog pin to read voltage

void setup() {
  lcd.init();
  lcd.backlight();
  lcd.setCursor(0, 0);
  lcd.print("Piezo Voltage:");
}

void loop() {
  int sensorValue = analogRead(sensorPin); // 0–1023
  float voltage = (sensorValue * 5.0) / 1023.0; // in Volts
  int millivolts = voltage * 1000; // for comparison


  lcd.setCursor(0, 1);

  if (millivolts < 1000) {
    lcd.print(millivolts);
    lcd.print(" mV     "); // Add spaces to clear extra chars
  } else {
    lcd.print(voltage, 2); // Show 2 decimal places
    lcd.print(" V      ");
  }
  delay(500); // Update every 0.5 seconds
}
```

APPENDIX D
DATASHEET OF COMPONENTS

Transparent Acrylic sheet - 1 pic

35mm Piezo discs - 8

Arduino UNO - 1

LCD I2C display - 1

Mini Breadboard - 1

Hookup wires -

Jumper wires -

10uf capacitor - 2

All resistors - 1 k ohom

1N4007 diodes - 4

Glue gun -

18650 cell holder - 1

18650 cells - 2

soldering kit