FOOTSTEP POWER GENERATION USING PIEZOELECTRIC SENSORS

Thesis submitted for the undergraduate degree in Mechanical Engineering at the University of Central Punjab

Project Members:
Asfand Yar: L1F19BSME0054
Shahzeb Ali: L1F19BSME0066
Muhammad Talha Khan: L1F19BSME0072

Project advisor:
Ahmad Farid Abbas

Session 2019-2023
Department of Mechanical Engineering,
University of Central Punjab, Lahore Pakistan

FOOTSTEP POWER GENERATION USING PIEZOELECTRIC SENSORS

Thesis submitted for the undergraduate degree in Mechanical Engineering
at the
University of Central Punjab

Internal Examiner:

Name and Signature: ____________________________

____

External Examiners:

Signature: ________________________________

Session 2019-2023
Faculty of Engineering,
University of Central Punjab, Lahore Pakistan

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

In today's world, electrical energy is of paramount importance for human survival, given the exponential growth of the global population and the corresponding increase in electricity demand. However, many traditional energy resources have been depleted and wasted. Consequently, researchers are urgently seeking alternative methods to generate energy with minimal consumption. One promising approach involves harvesting energy from human motion, specifically by capturing the mechanical vibrations produced during walking. This research paper presents an effective solution by utilizing a low-power setup to harness energy from these vibrations. A piezoelectric transducer is employed to detect and convert the force exerted by a person's footstep into electrical energy. By connecting the transducers in a parallel configuration and encapsulating them within a tile composed of rubber and acrylic layers, maximum stress and foot traffic can be utilized to maximize the electricity generated. To extract the maximum electrical output. The energy is then used to charge a battery, which can subsequently power various electronic devices.

DEDICATION

"To our respective parents, who have been our constant source of inspiration. They have given us the drive and discipline to tackle any task with enthusiasm and determination. Without their love and support this project would not have been possible."

SUSTAINABLE DEVELOPMENT GOALS

ABOUT:

The Sustainable Development Goals (SDGs), also referred to as the Global Goals, were globally embraced by the United Nations in 2015 to address poverty eradication, environmental protection, and the promotion of peace and prosperity for all by 2030. These 17 goals acknowledge the need for a harmonious integration of social, economic, and environmental sustainability, recognizing that actions in one domain have implications for others.

Figure 1 17 UN SDGs

OUR PROJECT OF FOOTSTEP POWER GENERATION USING PIEZOELECTRIC SENSORS MAPS WITH THE FOLLOWING UN SUSTAINABLE DEVELOPMENT GOALS:

- Goal 7: Affordable and Clean Energy
- Goal 9: Industry, Innovation and Infrastructure
- Goal 11: Sustainable Cities and Communities

MAPPING WITH COMPLEX ENGINEERING PROBLEM ATTRIBUTES

OUR PROJECT OF FOOTSTEP POWER GENERATION USING PIEZOELECTRIC SENSORS MAPS WITH THE FOLLOWING COMPLEX ENGINEERING PROBLEM TRAITS:

Table 1: Complex Engineering Problem Traits That Map With Our Project

WP1: Depth of knowledge required	WK3: Engineering fundamentals WK4: Engineering specialization
WP3: Depth of analysis required	Requires abstract thinking, originality in analysis to formulate suitable models.
EP2: Judgement (Professional Competency)	Requires judgement in decision making.

CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION:

Throughout history, fossil fuels have served as the predominant energy source for humanity. However, their rapid depletion has necessitated the exploration of alternative, environmentally-friendly energy sources that can meet the demands of our modern society. Common physical activities such as walking, jogging, running, and dancing require significant amounts of energy, resulting in body heat and sweat. This energy, which is typically wasted, can be captured and repurposed for practical use. Piezoelectricity, a method of generating electricity through mechanical vibrations, offers a promising solution. By employing piezoelectric transducers, which are electromechanical converters, we can harness the ambient vibrations produced during human locomotion. In this research paper, we propose replacing regular tiles with piezoelectric tiles to capture and convert these vibrations into electrical signals. The amount of energy generated depends on factors such as the frequency of pedestrian movement and the specific piezoelectric technology employed. Lead Zirconate Titanate crystals were utilized as the piezoelectric material in our study. Harvesting energy from human motion presents an appealing approach to obtain clean and sustainable energy.

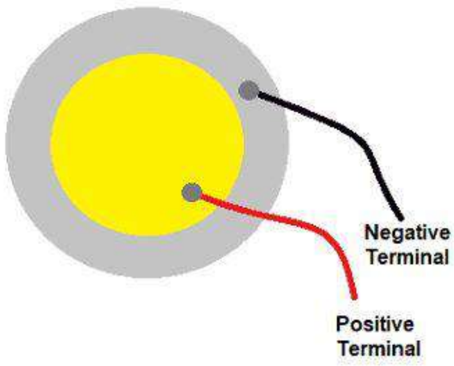


Figure 2: Piezoelectric Transducer

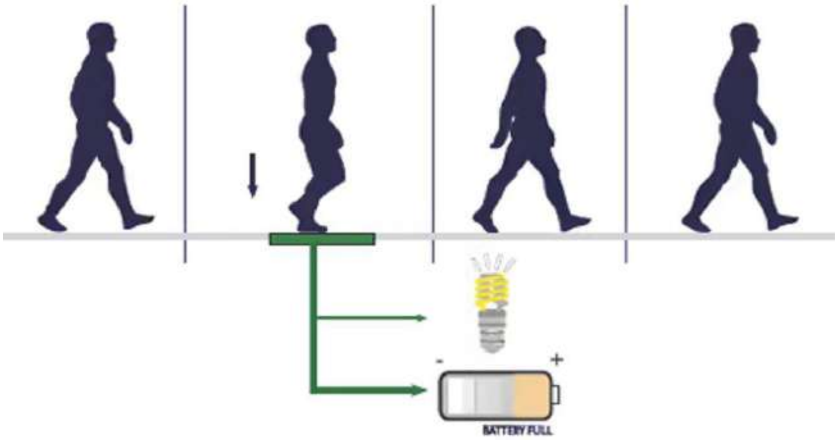


Figure 3: Demonstration of Footstep Power Generation

1.2 PROBLEM STATEMENT:

The power system has been pushed beyond its limits due to the increase in power demand and loads, resulting in inefficiency and complexity in operation. This has also had adverse effects on the environment, leading to a growing need for sustainable green energy. However, the availability of energy is not sufficient to meet the demand. Foot stepping is one of the most rapid activities in human life, generating large amounts of kinetic energy in the form of pressure force at crosswalks, schools, colleges, universities, offices, shopping centers, and market areas. This human energy source has not yet been fully utilized, but can be harnessed to power voltage loads. This study presents the design and implementation of a tile constructed with piezoelectric transducers, which generate electrical pulses and harvest the energy generated by human footsteps. This provides a power production system that utilizes a non-conventional, clean energy source.

1.3 AIM:

- Harnessing wasted energy of footsteps.
- A workable, economical, and sustainable alternative.
- Environmentally-safe.

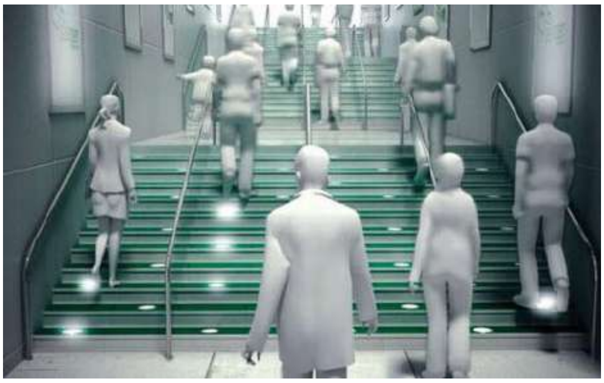


Figure 4 Application of The Footstep Power Generation System.

CHAPTER TWO: LITERATURE REVIEW

2.1 ENERGY HARVESTING FUNDAMENTALS:

2.1.1 CONCEPT OF PIEZOELECTRICITY:

Piezoelectric materials belong to the category of ferroelectric materials, which are characterized by possessing a molecular structure that demonstrates local charge separation or an electric dipole. Within these materials, electric dipoles are initially randomly oriented. However, when a strong electric field is applied and the material is heated above its Curie temperature, the dipoles can be realigned through a process called polling. This polling results in the material acquiring a polarization and exhibiting the piezoelectric effect. The mechanical and electrical behavior of a piezoelectric material can be mathematically described by two linear constitutive equations, which involve two mechanical and two electrical variables. The direct and converse effects of piezoelectricity can be effectively modeled using matrix equations, as specified in the IEEE Standard on Piezoelectricity and ANSI Standard 176-1987 :

$$\text{Direct Piezoelectric effect: } D = \{e\}^T\{S\} + \{\alpha^S\}\{E\}$$

$$\text{Converse Piezoelectric effect: } T = \{c\}^E\{S\} + \{e\}\{E\}$$

Here, {D} is the electric displacement vector,{T} is the stress vector, [e] is the dielectric permittivity matrix, $\{c\}^E$is the matrix of elastic coefficients at constant electric field strength, {S} is the strain vector, $\{\alpha^S\}$ is the dielectric matrix at constant material strain, {E} is the electric field vector.

Once a material is poled, the application of an electric field can cause it to either expand or contract. However, the orientation of the electric field on different surfaces of the material can result in varying stress and strain responses. Therefore, a sign convention is necessary to define the piezoelectric properties, enabling the application of electric potential in three different directions. There are two main types of piezoelectric materials: stack configurations, which operate in the -33 mode, and benders, which operate in the -31 mode. Early experiments conducted in 1880 by Pierre and Jacques Curie explored the piezoelectric potential of crystals such as tourmaline, quartz, topaz, cane sugar, and Rochelle salt. Among these, quartz and Rochelle salt exhibited the most significant piezoelectricity. Developments in the mathematics of direct and converse piezoelectricity took place between 1880 and World War I. Ferroelectric ceramics, specifically Barium Titanate, were invented during World War II. In 1969, Polyvinylidene Fluoride (PVDF) demonstrated strong piezoelectricity. Later, Lead Zirconate Titanate (PZT), studied by Shirane at the Tokyo Institute of Technology, emerged as the most widely used piezoelectric ceramic material due to its improved reproducibility and faster propagation speed compared to barium titanate ceramics and PVDF. The majority of fabricated and tested piezoelectric generators employ variations of PZT, which is also popular for piezoelectric energy harvesting due to its high piezoelectric coefficient and dielectric constant, resulting in greater power output for a given input acceleration. Additionally, PZT is readily available and widely used as a piezoelectric sensor [1].

Table 2: Piezoelectric Material

Natural Piezoelectric Material	**Synthetic Piezoelectric Material**
Quartz (most used)	Lead Zirconate Titanate (PZT)
Rochelle Salt	Zinc Oxide (ZnO)
Topaz	Barium Titanate (BaTiO3)
TB-1	Piezoelectric ceramics Barium titanate
TBK-3	Calcium barium titanate
Sucrose	Gallium orthophosohate (GaPO4)
Tendon	Potassium niobate (KNbO3)
Silk	Lead titanate (PbTiO3)
Enamel	Lithium tantalite (LiTaO3)
Dentin	Langasite (La3Ga5SiO14)
DNA	Sodium tungstate (Na2WO3)

2.1.2 PRINCIPLE OF OPERATION:

The initial state of a piezoelectric crystal is electrically neutral, with an equal number of positive and negative charges resulting in a symmetrical charge distribution and no net electric dipole. However, applying pressure or an external load to the crystal disrupts this symmetry, leading to the creation of a net polarization and the generation of an electric pulse. To achieve maximum power extraction, the rectified voltage should be half of the no-load voltage in a full bridge rectification configuration with a capacitor for filtering purposes. Piezoelectric materials exhibit two effects: the direct effect and the converse effect. The direct effect is observed in crystalline materials like quartz and Rochelle salt, which generate electricity when pressure or a load is applied. This effect allows these materials to be used as sensors. In contrast, the converse effect enables the material to function as an actuator, meaning it undergoes deformation in response to an electrical signal [2].

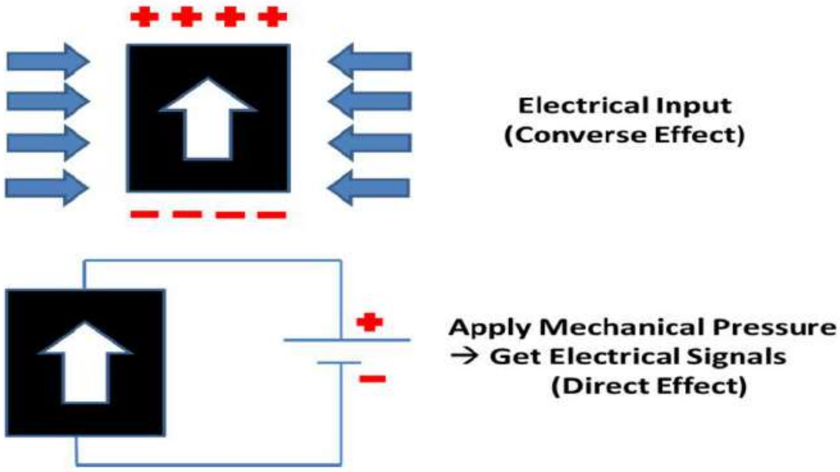


Figure 5 Piezoelectric Effect Block Diagrams

2.2 RESEARCH METHODOLOGY:

Previous studies have employed Lead Zirconate Titanate (PZT) piezoelectric transducers to capture the kinetic energy generated by footsteps. The output voltage of these transducers depends on the ceramic's structure and the magnitude of strain and stress applied to it. The transducer, with a crystalline structure and a diameter of 0.5m, typically generates an output voltage ranging from 0-12V. However, upon immediate impact, it can reach up to 30V with an output current of approximately 5mA. Two shapes of PZT piezoelectric transducers, circular and square, have been examined. The circular shape proves more suitable for absorbing stress or strain at the center of the transducer, while the square shape yields higher output voltage when stress or strain is applied at the tip. Based on testing, the circular shape was deemed the most appropriate transducer for capturing footsteps due to its ability to generate higher output voltage. This can be attributed to the deflection in its structure when subjected to footstep pressure. The piezoelectric transducer can be connected in series or parallel, with both configurations providing satisfactory output values for voltage and current. The transducer's output is in AC form and must be rectified into DC form before being stored in storage components such as batteries or capacitors and supplied to DC loads [3].

2.3 WORKING MECHANISM:

- Piezoelectric transducers are used to translate mechanical input into electrical energy.
- The force applied to the disc determines how much power is generated.
- The voltage generated as a result of the charges' potential differences is AC.

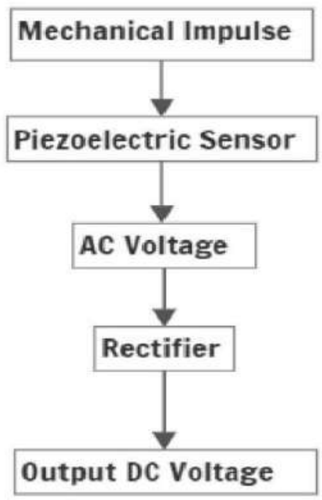


Figure 6: Working Mechanism

2.2 ACQUIRED DATA:

2.2.1 FEATURE & SPECIFICATIONS OF PZT TRANSDUCER:

Impedance: Maximum 500Ω
Voltage: Maximum peak-to-peak voltage of 30V
Operating temperature range: -20°C to 60°C
Storage temperature range: -30°C to 70°C
Low soldering temperature requirement
Strain sensitivity: Generates 5V output per microstrain (με)
Material: Primarily composed of quartz, which is commonly utilized in these devices.

2.2.2 EXPERIMENTAL RESULTS:

At normal generate, a 0.05-meter-diameter piezoelectric transducer produces an output voltage of around 0–12 [3] . It can become as high as 30V and 5mA when there is an instant impact [3]. A piezoelectric floor energy harvesting system may generate up to 71.20 V of AC voltage from a tile made up of 20 pieces of parallel-connected piezoelectric transducers. The average voltage generated is 63.98 V [4]. An array of 20 PZT energy harvesters linked in parallel may generate an average power of 0.0604 watt per footstep [4].

The voltage output of six piezoelectric transducers coupled in series-parallel connection was studied using foot pressure or pumping:

Subject	Weight (kg)	Time (sec)			
		5 sec	10 sec	15 sec	20 sec
Subject 1	45	1.98 V	2.15 V	2.80 V	3.78 V
Subject 2	50	0.83 V	1.23 V	2.38 V	3.12 V
Subject 3	55	1.76 V	2.73 V	4.66 V	5.65 V
Subject 4	60	2.75V	4.59 V	5.31 V	6.06 V

Figure 7: The Weight and the Voltage Taken based on the Jump on the Piezoelectric.

A Low-drop regulator (LDO) is used to adjust voltage at the rectifier's output in a piezoelectric energy harvesting system. With a 3mV voltage ripple, the LDO's efficiency may reach a maximum of 90%. The suggested system's total effectiveness is 83.3% [5].

2.3 OPERATIONAL FINDINGS:

Table 3: Operational Findings

Generation Method	Energy Production (kWh/day)	Places of Harvest	Source
Piezoelectric Tiles	27	Macquarie University, Sydney, Australia	[5]
Piezoelectric Pavement	840	Avenida Boyacá Avenue and Calle 17, Bogota Colombia,	[5]
Piezoelectric Railways	2880	Israel	[5]
Piezoelectric Breakwaters	4	Cantabria Santander, Spain	[5]

2.3.1 PIEZOELECTRIC TILES:

By applying the principles of piezoelectric generation, we can create micro power generation systems that harness the movement of people walking on tile-like surfaces, such as brick floors. There are two methods of generating power using piezoelectric modules: the hitting method and the vibrating method. The hitting method involves direct loading on the piezoelectric modules, while the vibrating method utilizes superficial loads, resulting in greater durability and applicability across larger areas. The vibrating method, due to its larger amplitude, is suitable for installations in broader spaces, making it a source of macro power. Various locations like crosswalks, office buildings, shopping malls, and even discotheques are well-suited for implementing this technology since people frequently walk in these areas. This innovative approach to generating clean energy is highly promising as people will always be in motion, and walking will perpetually serve as the raw material for energy generation [5].

2.3.2 PIEZOELECTRIC PAVEMENT:

The piezoelectric approach involves installing devices on asphalt surfaces that can convert the pressure and vibrations produced by passing vehicles into electrical power. However, this energy needs to be rectified and transformed to make it storable and usable. With the significant increase in the number of vehicles in recent decades, constructing new roads has become a priority. Some countries, such as Israel, Japan, the United States, and Colombia, have implemented specialized road sections designed to convert the vibrations caused by cars into energy. This application is particularly intriguing because a single truck, for instance, can generate a substantial amount of potential energy while traveling on a road equipped with a layer of piezoelectric material beneath the asphalt. This layer also serves the purpose of collecting data on parameters like speed, weight, and frequency of passing vehicles. Literature suggests that even one-kilometer stretches of road using piezoelectric technology can achieve high energy generation capacity. Prototype tests of energy harvesting techniques have demonstrated practical applications, showcasing the significant potential of utilizing these devices along vehicle transit routes. Moreover, the potential for energy generation is even greater on roads frequented by heavy vehicles, to the extent that independence from the power grid can be achieved, allowing for indirect recovery of the investment in these piezoelectric devices [5].

2.3.3 PIEZOELECTRIC RAILWAYS:

Piezoelectric elements can be utilized on train tracks to generate electricity, similar to the power generation method employed on roads using pavements with these elements. The advantage of implementing this approach on railways is that pressure is consistently applied at the same location since the piezoelectric devices are positioned in the joints that form the support structure of the rails. These devices are connected to other equipment to capture the generated energy, which can be utilized to power trains, signals, or even contribute to the general power grid. It is estimated that the passage of trains can generate a minimum of 120 kWh of clean energy while also providing valuable information such as speed, weight, and the number of wheels. This method has the potential to create self-sustaining signaling systems and reduce the reliance on the electricity network, particularly for electric trains, by harnessing vibrations and pressure at specific points along the rail tracks [5].

2.3.4 PIEZOELECTRIC BREAKWATERS:

Wave energy represents a substantial and environmentally friendly potential energy source that can be effectively captured using piezoelectric devices. Given that approximately 70% of the Earth is covered by oceans, there are significant opportunities to generate electricity from ocean waves, such as by deploying devices on buoys or offshore floats. However, for these devices to be economically feasible, they need to be of considerable size while minimizing their impact on the marine ecosystem. Additionally, this system can incorporate useful sensors for navigation purposes. The abundance of wave energy offers the potential for reducing the need for extensive power line installations in coastal areas without existing electricity infrastructure. Furthermore, wave energy is a clean and renewable source that can be harnessed sustainably, contributing to a greener and more sustainable energy mix [5].

CHAPTER THREE: RESEARCH DESIGN

3.1 TILE DESIGN:

The composition of the tile includes rubber mats, acrylic sheets, and piezoelectric transducers, as stated in reference [4]. The rubber mats are used for two purposes: first, to prevent slippage, and second, to safeguard the acrylic sheets. The employed tile was produced of molded acrylic to assure its load bearing capacity, due to the material's strength and low weight. The tile measures a typical 12" x 12" (0.3048 m by 0.3048 m) dimension. Each piezoelectric sensor utilized has a diameter of 27mm (0.027 m), and there are 25 Lead Zirconate Titanate piezoelectric transducers in use. The foam mats are 1 mm thick (0.001m thick). The utilized acrylic sheets are 5mm (0.005m) thick. The tile is 20 mm thick overall (0.020 m).

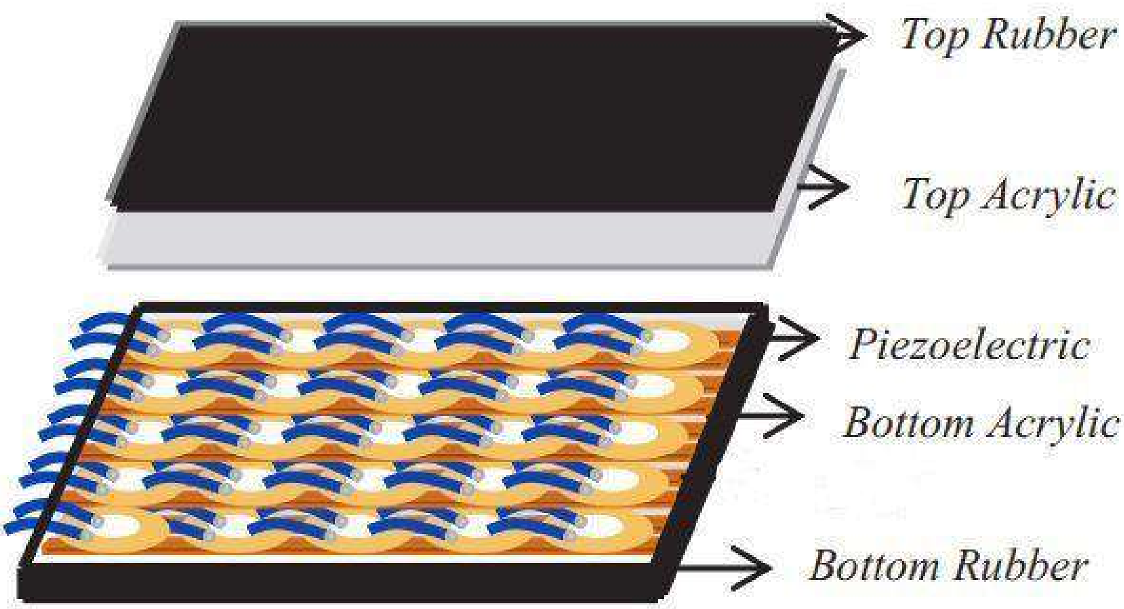


Figure 8: Tile Design [4]

3.1.1 3D MODEL:

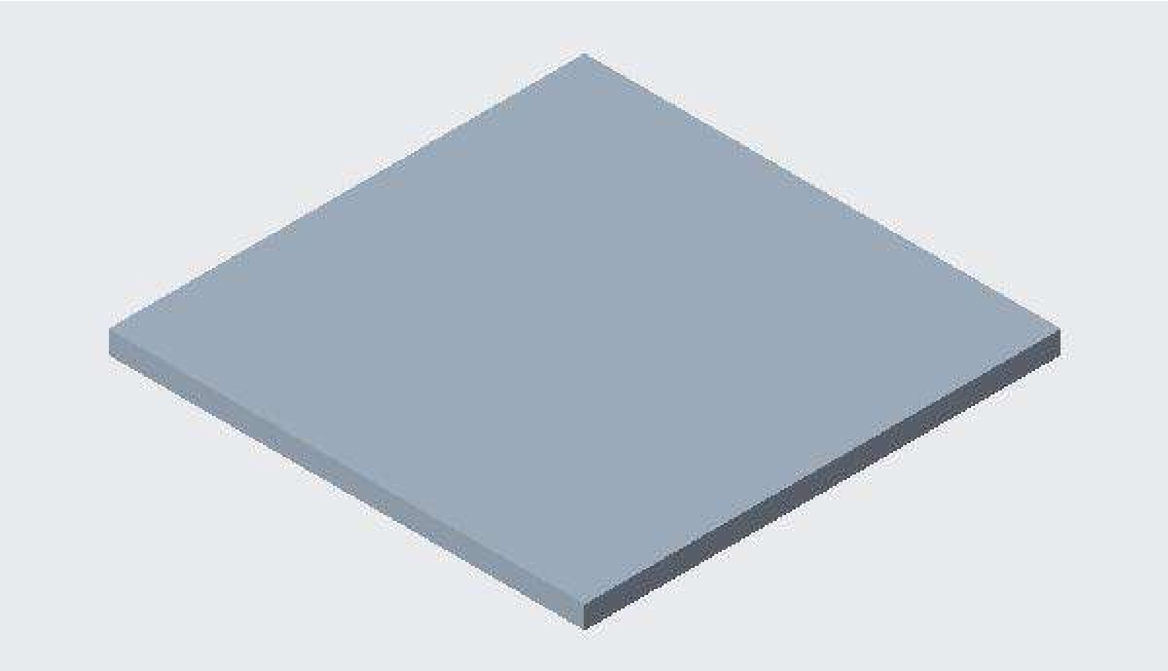


Figure 9: First Layer of Rubber Mat

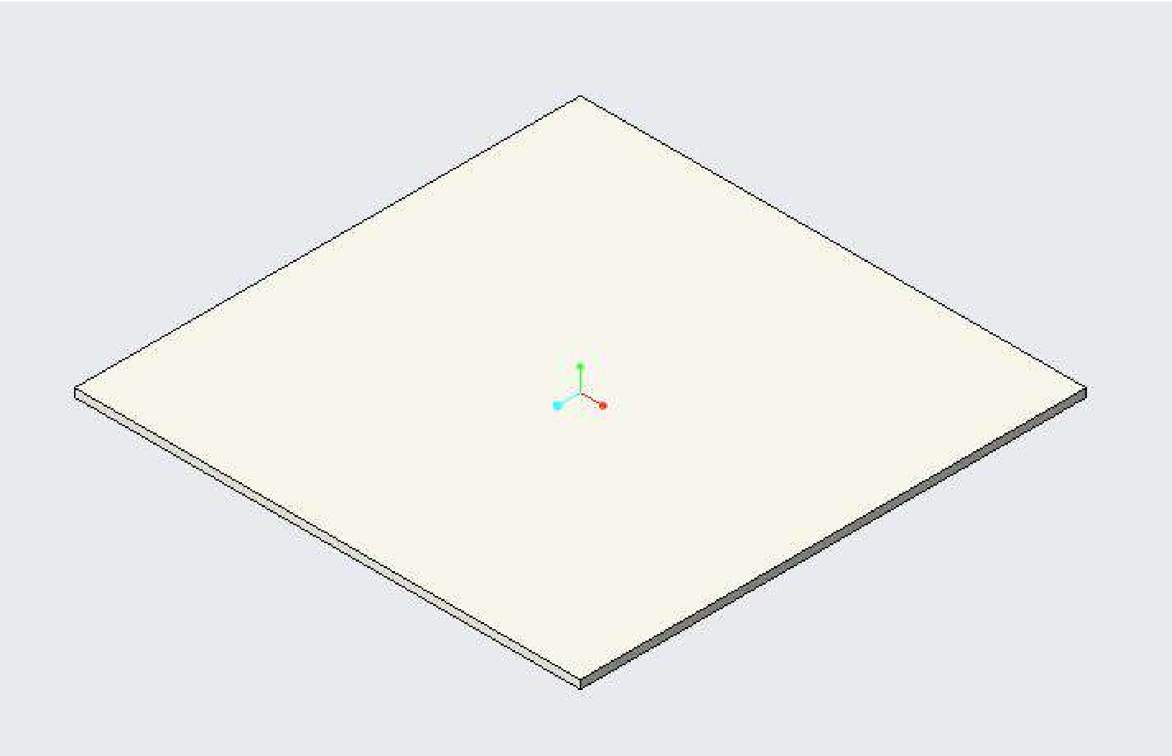


Figure 10: Second Layer of Acrylic Sheet

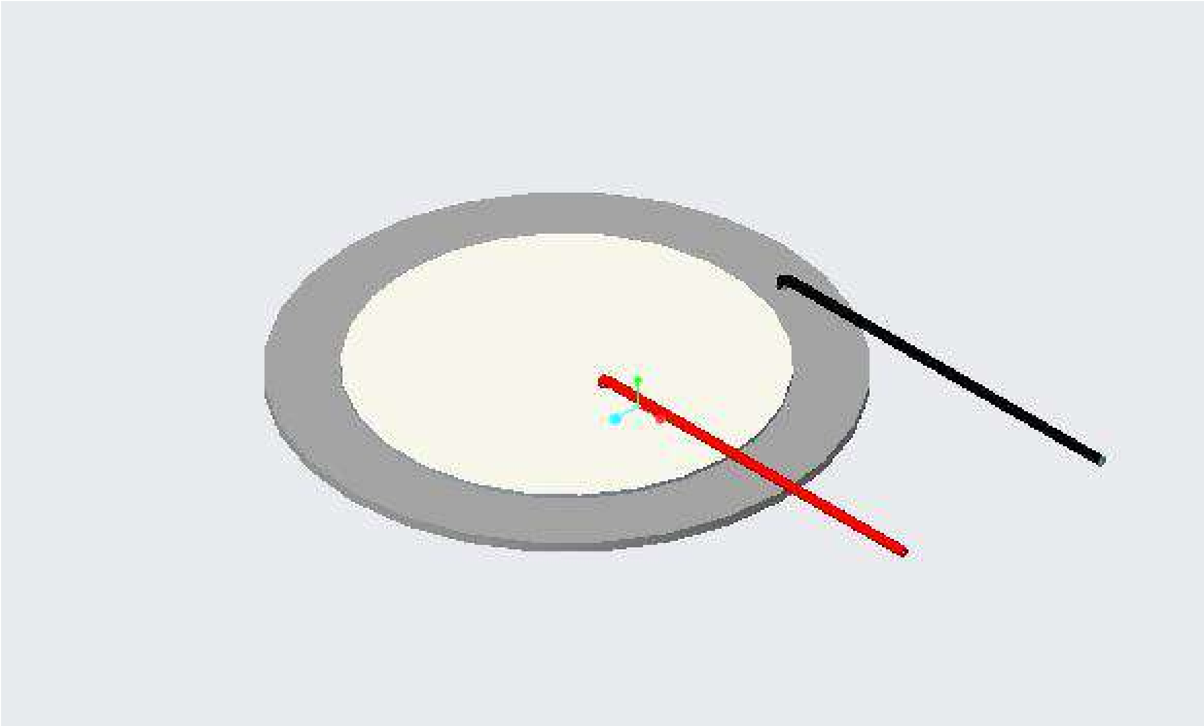


Figure 11: Piezoelectric Sensor

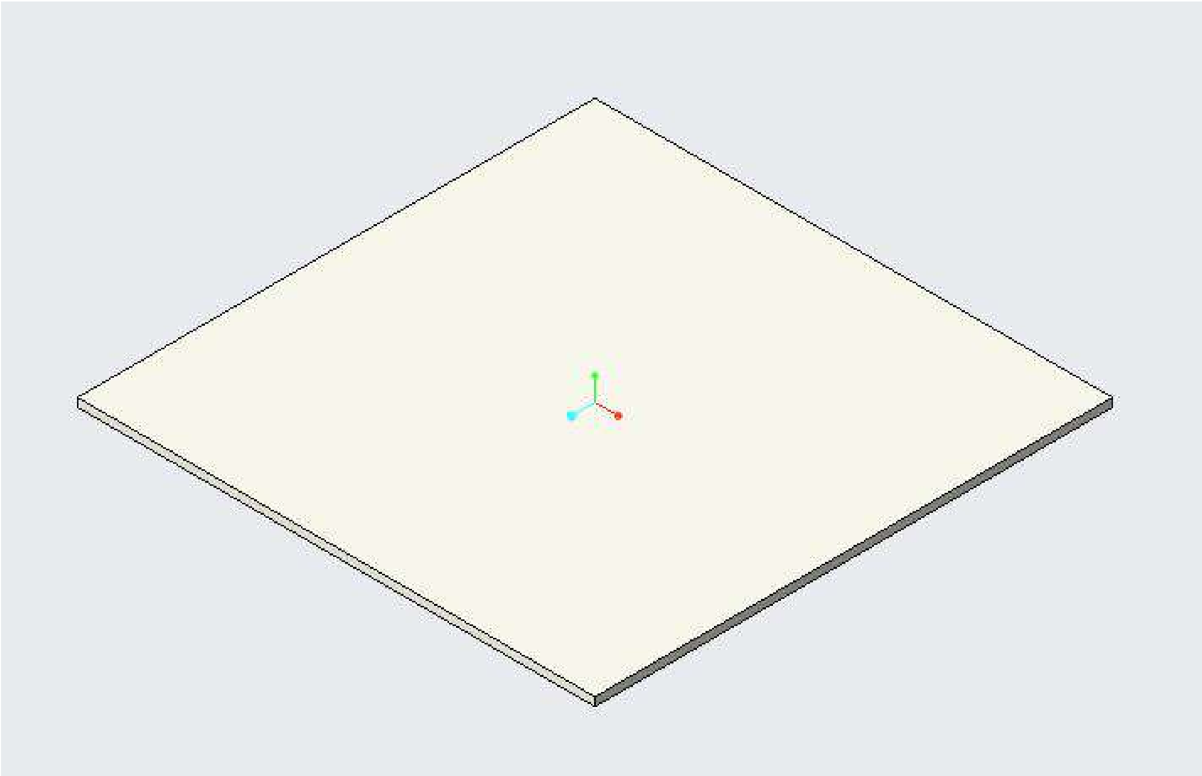


Figure 12: Fourth Layer of Acrylic Sheet

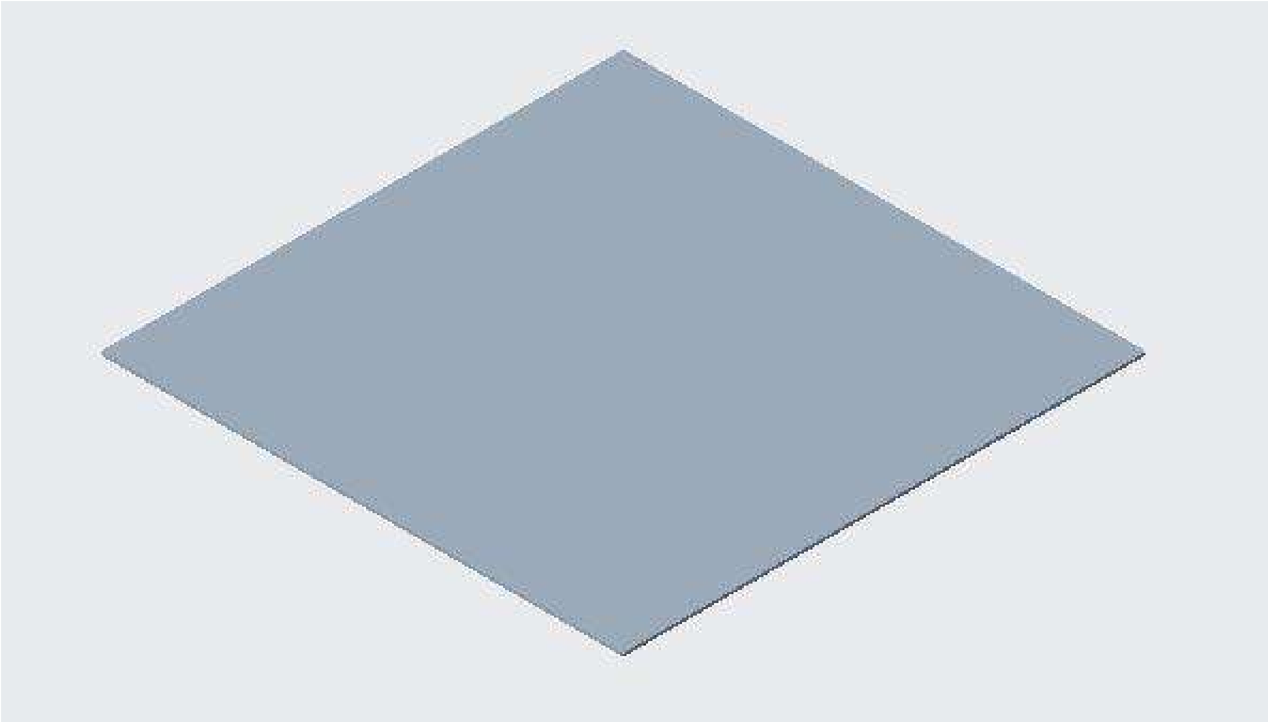


Figure 13: Fifth Layer of Foam Mat

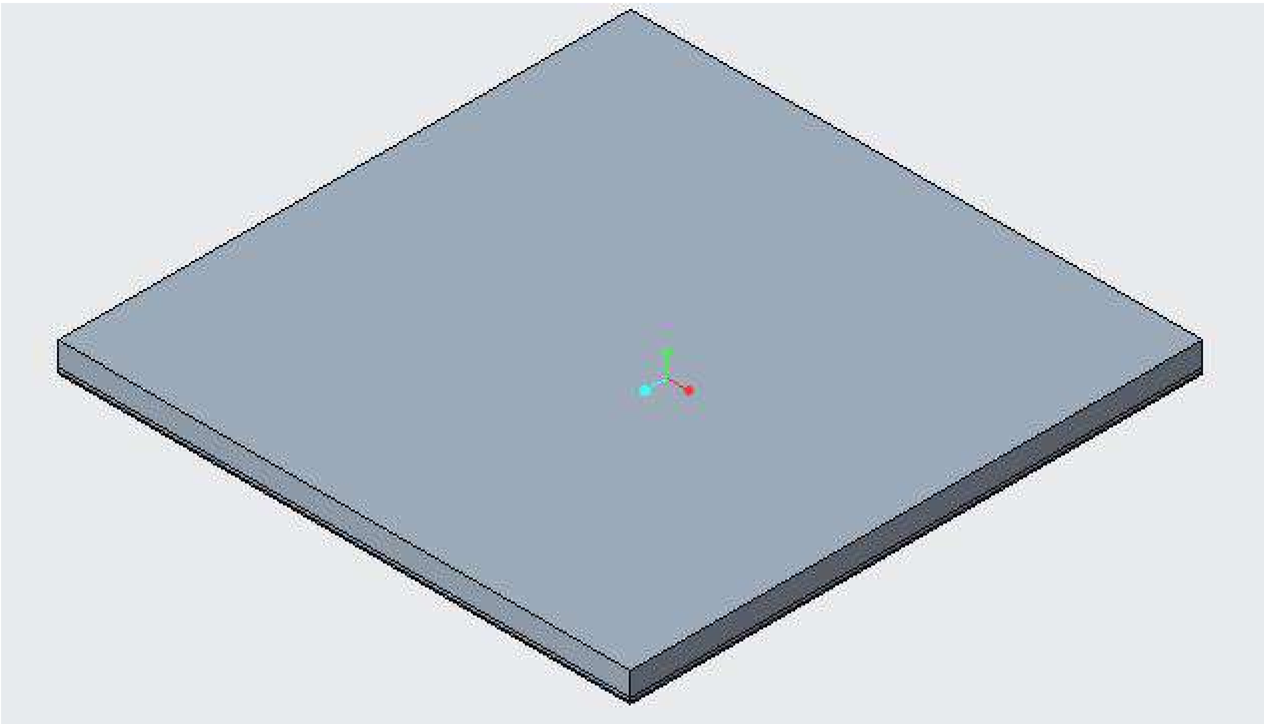


Figure 14: Tile

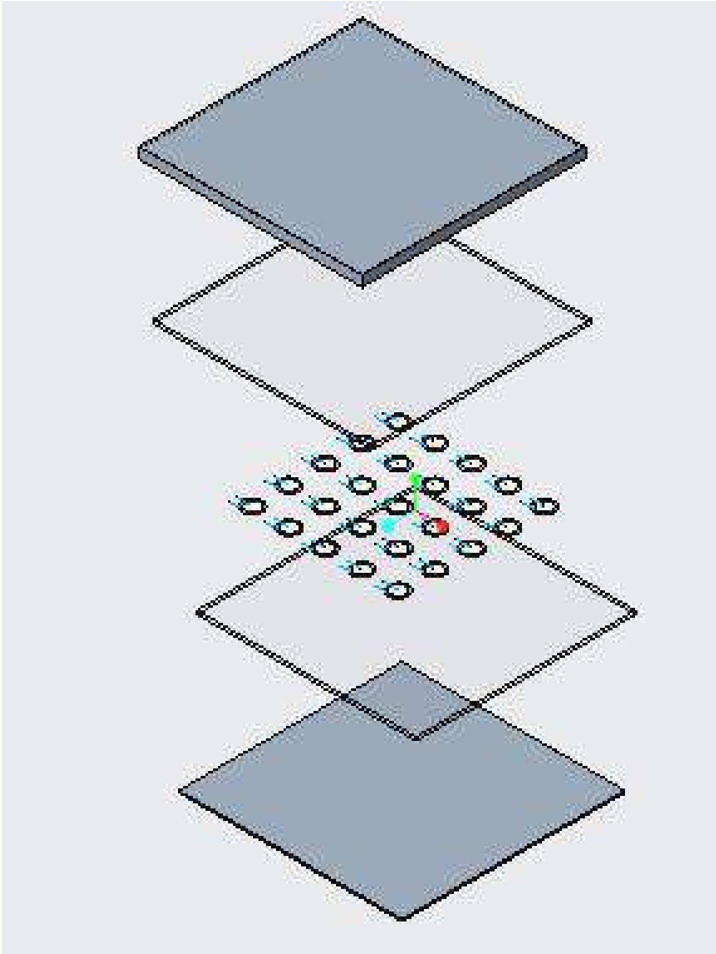


Figure 15: Exploded View of Tile

3.1.2 DIMENSIONS:

All dimensions are in inches.

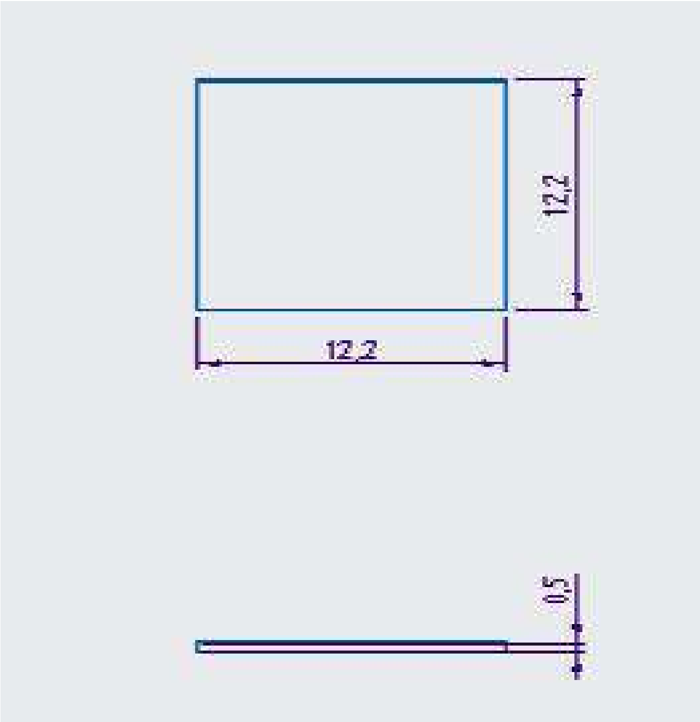


Figure 16: First Layer of Foam Mat

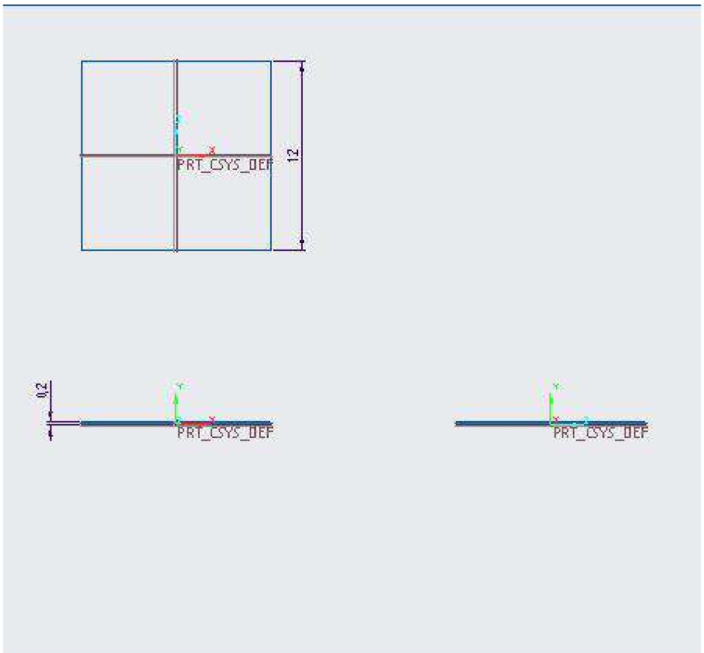


Figure 17: Second Layer of Acrylic Sheet

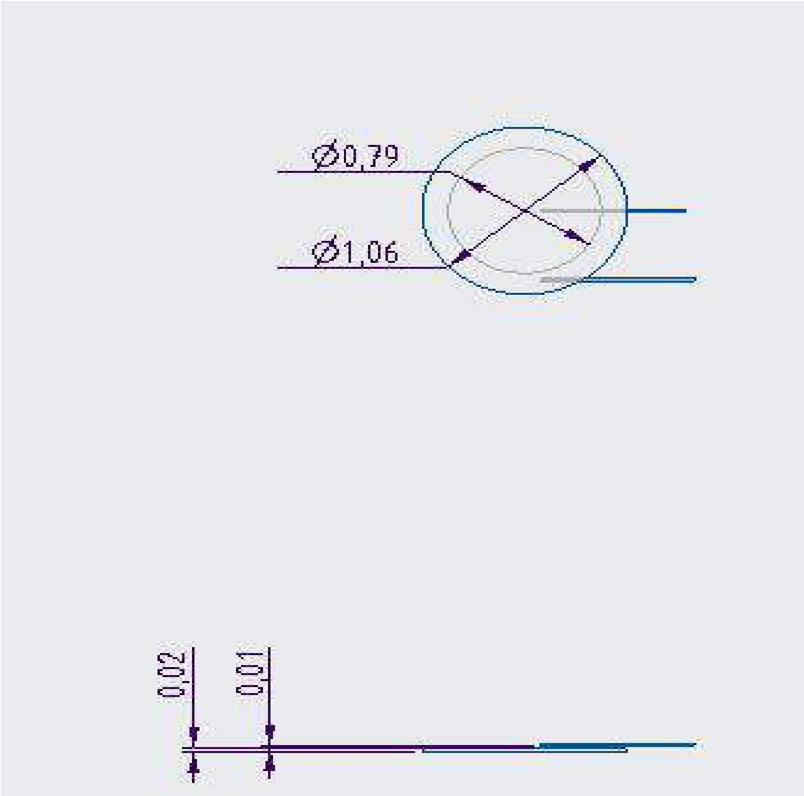


Figure 18: Piezoelectric Sensor

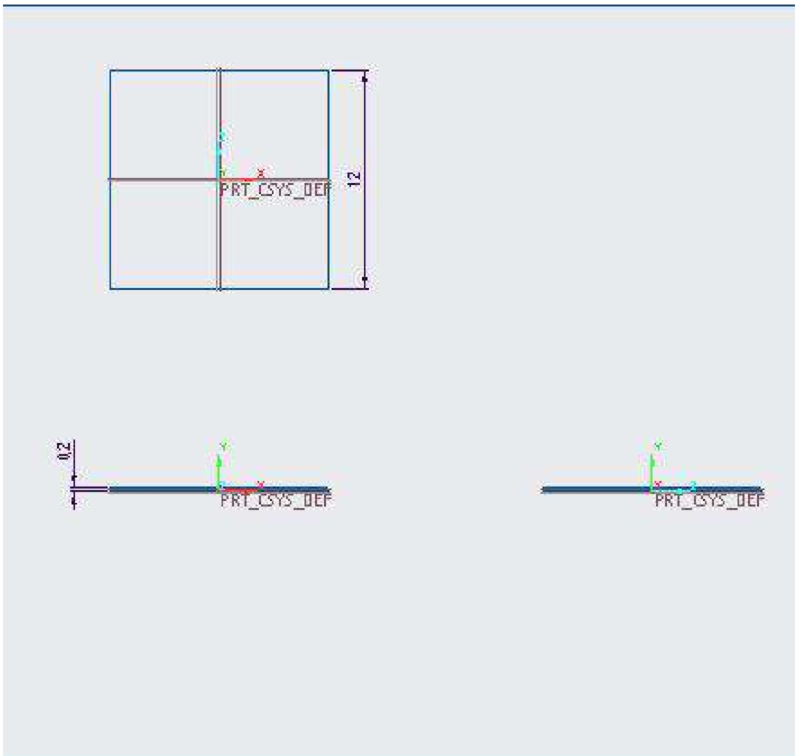


Figure 19: Fourth Layer of Acrylic Sheet

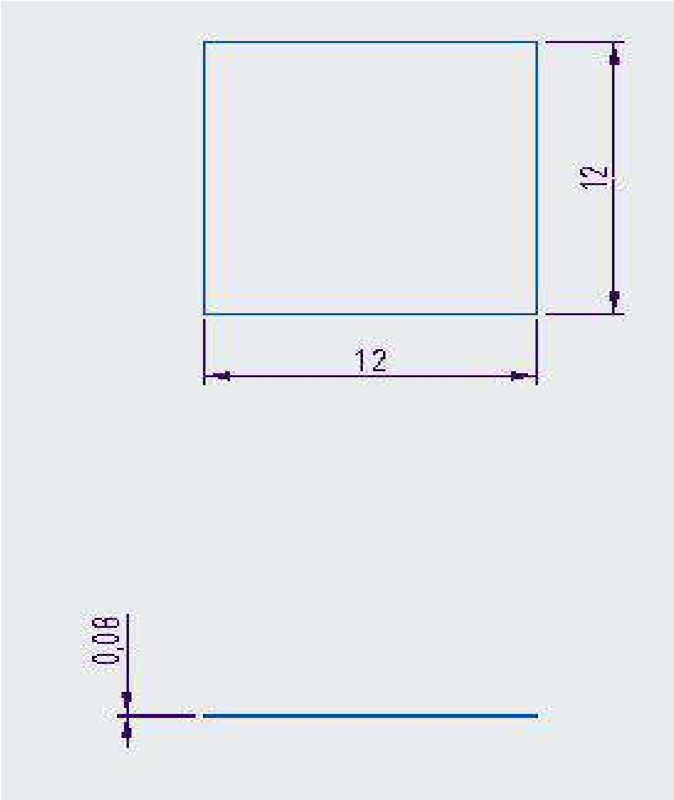


Figure 20: Fifth Layer of Foam Mat

3.2 CIRCUIT DESIGN:

3.2.1 OVERVIEW:

The system consists of five rows of PZTs, each with five sensors and wired in parallel. This configuration allows the PZTs to create voltage by walking. The voltage created by the PZTs is sent into the HEX inverter, and the amplified output signal from the HEX inverter is fed into the boost converter, which boots the voltage and gives it to the battery. Finally, a phone charging module is connected to the battery's output.

3.2.2 SELECTED COMPONENTS:

Table 4: Component Specifications

Component	Specification
PZT	Lead Zirconate Titanate
HEX Inverter	IC 4069
Boost Converter	XL6009
Battery	12 V DC
Phone Charging Module	Input voltage range of 4.5-40V Output voltage of 5V

3.2.3 REASON FOR USING SELECTED COMPONENTS:

PZT is chosen for the piezoelectric energy harvester due to its superior piezoelectric coefficient and dielectric constant. These properties enable it to produce greater power output in response to a given input acceleration. The boost converter requires at least 3.5V to boost the voltage and also requires a lag to function, hence the necessity of the HEX inverter (High Impedance Amplifier). The boost converter's enhanced voltage is adjustable and can be set to fully charge the battery. Step down Module Practical USB charger Buck Converter is employed because it has an input voltage range of 4.5-40V and an output voltage of 5V required to charge a phone.

3.2.4 CIRCUIT CONNECTION:

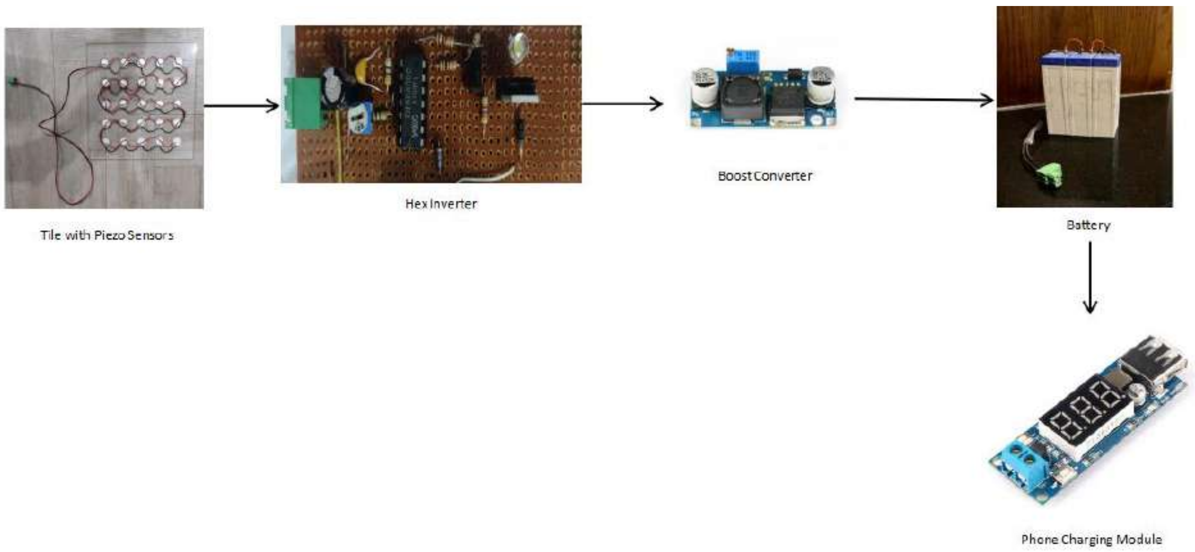


Figure 21: Block Diagram of Circuit

Table 5: Connection of Components

Component	Connection
PZTs	Parallel Combination
HEX Inverter	Series with Piezoelectric Gird
Boost Converter	Series HEX Inverter
Battery	Series with Boost Converter
Phone Charging Module	Series with Battery

3.2.5 DESIGN OF CIRCUITRY USING PROTEUS:

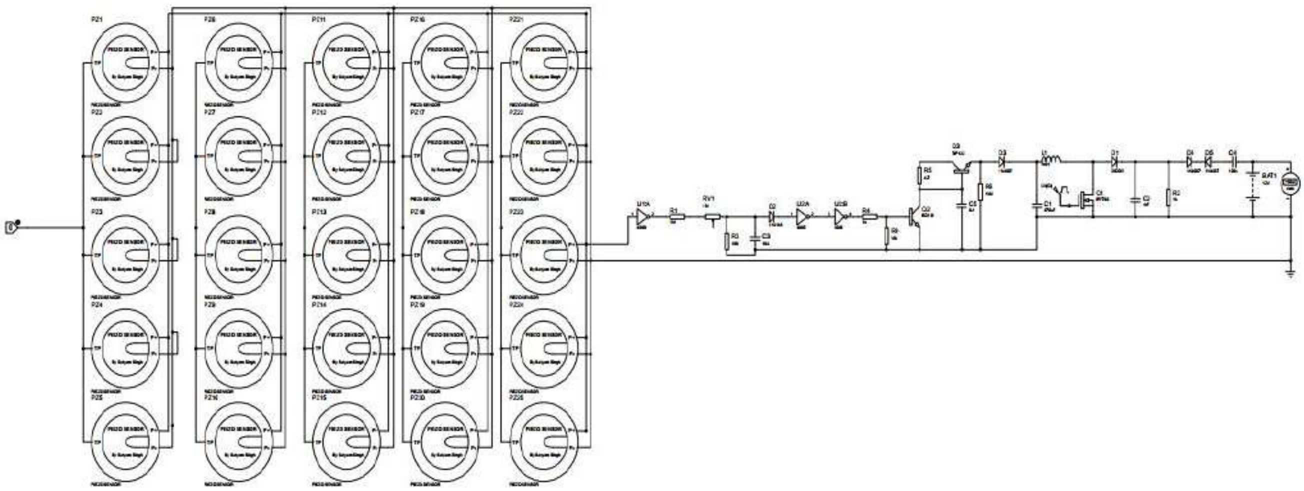


Figure 22 Proteus Design of Circuitry

CHAPTER FOUR: FINDINGS/RESULTS

4.1 CALCULATIONS:

	Density $\rho \times 10^3$ (kg/m3)	Speed of sound C_s ((10^3m/sec)	Dielectric constant ϵ	Piezoelectric modulus $d \times 10^{-12}$ coulombs/newton	Loss tangent $\tan \times 10^2$	Electromechanical coupling factor k	$k^2/\tan\delta$	Remarks
Quartz	2.6	5.47[11]	4.5[11]	2.31[11]	<0.5	0.095	>2.0	x-cut
Ammonium dihydrogen phosphate (ADP)......	1.8	3.25[33]	15.3	24.0[36]/2	<1	0.28	>8	cut at 45° to z-axis
Lithium sulfate.........	2.05	4.7[33]	10.3[22]	16.3[22]	<1	0.30	>10	y-cut
Rochellesalt.........	1.77	3.1(22)	350[11]	275	>5	0.65	>8	cut at 45° to x-axis; substance decomposes at T>55°C
Antimony sulfoiodide.....	5.2	1.5[33]	2,200[33]	150[31]/1,300[33]	5–10	0.8[33]	6.4	
Piezoelectric ceramics Barium titanate (TB-1).	5.3	4.6/4.9	1,500	45/100	2–3	0.2/0.5	1.3/8.0	
Calcium barium titanate (TBK-3)	5.4	4.7/4.4	1,200	51/113	1.3–2.5	0.17/0.37	1.2/5.5	
Group of lead titanate zirconates								
TsTs-23.........	7.4	3.2/3.0	1,100	75/150	0.75–2.0	0.2/0.41	2/8.4	
TsTBS-3	7.2	3.5/3.2	2,300	160/320	1.2–2.0	0.32/0.65	5.1/21	
TsTSNV-1	7.3	2.9/2.6	2,200	200/430	1.9–9.0	0.34/0.72	1.3/5.7	
PZT-5H.........	7.5	2.8/2.6	3,400	274/590	2.0–9.0	0.39/0.75	1.7/6.2	data from Clevite Corporation (USA)
PZT-8..........	7.6	3.4/3.1	1,000	93/217	0.4–0.7	0.29/0.62	1.2/5.5	data from Clevite Corporation

Figure 23: Properties of Piezoelectric Materials [7]

Mechanical Properties	Metric	English
Hardness, Barcol	49.0 - 50.0	49.0 - 50.0
Hardness, Rockwell M	94.0 - 105	94.0 - 105
Ball Indentation Hardness	175 MPa	25400 psi
Tensile Strength, Ultimate	62.0 - 83.0 MPa	8990 - 12000 psi
	40.0 - 110 MPa @Temperature -40.0 - 70.0 °C	5800 - 16000 psi @Temperature -40.0 - 158 °F
Tensile Strength, Yield	64.8 - 83.4 MPa	9400 - 12100 psi
Elongation at Break	3.00 - 6.40 %	3.00 - 6.40 %
Modulus of Elasticity	2.76 - 3.30 GPa	400 - 479 ksi
Flexural Yield Strength	98.0 - 125 MPa	14200 - 18100 psi
Flexural Modulus	2.96 - 3.30 GPa	429 - 479 ksi
Compressive Yield Strength	110 - 124 MPa	16000 - 18000 psi
Compressive Modulus	2.76 - 3.03 GPa	400 - 440 ksi
Poissons Ratio	0.370	0.370
Shear Modulus	1.70 GPa	247 ksi
Shear Strength	25.5 - 62.1 MPa	3700 - 9000 psi
Izod Impact, Notched	0.160 - 0.220 J/cm	0.300 - 0.412 ft-lb/in
Izod Impact, Notched (ISO)	1.60 kJ/m²	0.761 ft-lb/in²
Charpy Impact Unnotched	1.20 - 2.17 J/cm²	5.71 - 10.3 ft-lb/in²
Coefficient of Friction	0.450 - 0.800	0.450 - 0.800
Compression Set	0.750 %	0.750 %

Figure 24: Mechanical Properties of Acrylic Sheet [8]

Product Attributes

TYPE	DESCRIPTION
Category	Audio Products Buzzer Elements, Piezo Benders
Mfr	Murata Electronics
Series	7BB
Package	Bulk
Product Status	Active
Frequency	4.6 kHz
Voltage - Input (Max)	-
Type	Feedback
Impedance	200 Ohms
Capacitance @ Frequency	18000pF @ 1kHz
Operating Temperature	-
Size / Dimension	1.063" Dia (27.00mm)

Figure 25: Product Attributes of Piezoelectric Sensor

4.1.1 VOLTAGE OF PIEZOELECTRIC SENSOR:

Calculation performed for a weight of 75 kg.

The force acting on the sensor can be calculated using the formula:
Force (F) = Mass (m) x Acceleration due to gravity (g)
where:
m = 75 kg (mass of the person)
g = 9.81 m/s² (acceleration due to gravity)

$$F = 75 \text{ kg} \times 9.81 \text{ m/s}^2$$
$$F = 735.75 \text{ N}$$

Piezoelectric coefficient (d_{33}):
The value used for the d_{33} coefficient of PZT sensors is 432 x 10^{-12} C/N (average value taken from figure attached)
Capacitance: 18000 pF (value taken from figure 25)

We can now calculate the voltage (V) using the piezoelectric coefficient (d_{33}), force (F), and capacitance (C):

$$V = \frac{d_{33} \times F}{C} \qquad [9]$$

$$V = (432 \times 10^{-12} \text{ C/N}) \times (735.75 \text{ N}) / (18000 \times 10^{-12} \text{ F})$$
$$V \approx 17.658 \text{ V}$$

The previously calculated voltage is if the entire force acts on a single piezoelectric sensor, However, If the total applied force on the acrylic sheet is 735.75 Newtons and there are 25 piezoelectric sensors evenly distributed under the sheet, we can calculate the force on a single sensor by dividing the total force by the number of sensors.

Force on a single sensor = Total force / Number of sensors
Force on a single sensor = 735.75 N / 25
Force on a single sensor ≈ 29.43 N

Therefore, each piezoelectric sensor would experience a force of approximately 29.43 Newtons when the total applied force on the acrylic sheet is 735.75 Newtons and there are 25 sensors evenly distributed. So the resultant voltage now comes out to be:

$$V = (432 \times 10^{-12} \text{ C/N}) \times (29.43 \text{ N}) / (18000 \times 10^{-12} \text{ F})$$
$$V \approx 0.706 \text{ V}$$

4.1.2 CURRENT AND RESISTANCE OF PIEZOELECTRIC SENSOR:

Next, we can calculate the current (I) by dividing the voltage (V) by the resistance (R). Since we don't have the resistance value, we'll calculate it using the formula:

$$R = \frac{1}{C\omega} \qquad [10]$$

Where:
R is the resistance
C is the capacitance
ω is the angular frequency

The angular frequency can be calculated using the formula:

$$\omega = 2\pi f$$

Where:
ω is the angular frequency
f is the frequency = 1 kHz (value taken from figure attached)
Calculating the angular frequency (ω):
Now:

$$\omega = 2\pi \text{ x } 1000$$
$$\omega \approx 6283.185 \text{ rad/s}$$

Now, we can calculate the resistance (R):

$$R = 1 / ((18000 \times 10^{-12}) \text{ x } (6283.185))$$
$$R \approx 8841.94\ \Omega$$

Finally, we can calculate the current (I) using Ohm's Law:

$$I = V / R$$

Current when an applied force of 735.75 N acts on a single piezoelectric sensor:

$$I = \frac{17.658}{8841.94}$$

$$I \approx 1.99 \text{ mA}$$

Current when the applied force of 735.75 N is equally distributed on 25 piezoelectric sensors i.e. 29.43 N on a single sensor:

$$I = \frac{0.706}{8841.94}$$

$$I = 0.0798 \text{ mA}$$

4.1.3 POWER GENERATED BY THE PIEZOELECTRIC SENSORS :

When the entire force acts on one sensor,

$$P = VI$$
$$P = (17.658)(0.00199)$$
$$P = 35 \text{ mW (per footstep)}$$

When the force is equally distributed,

$$P = (0.706)(0.0000798)$$
$$P = 0.056 \text{ mW (per foot step)}$$

Power produced by the entire tile:
25 parallel-connected piezoelectric sensors,
When the force is equally distributed,
So the current becomes = (0.0798 mA)(25) = 1.995 mA
Voltage remains same = 0.706 V

$$P = (0.706)(0.001995)$$
$$P = 1.408 \text{ mW (per footstep)}$$

When the entire force acts on one sensor,
So the current becomes = (0.00199 A)(25) = 0.04975 A
Voltage remains same = 17.658 V

$$P = (17.658)(0.04975)$$
$$P = 0.8785 \text{ W (per footstep)}$$

4.1.4 MAXIMUM LOAD BEARING CAPACITY OF ACRYLIC SHEET:

To calculate the maximum load-bearing capacity of an acrylic sheet, we need to consider its dimensions, thickness, and the Young's modulus of the material.

Calculating the maximum load-bearing capacity (P) of a rectangular plate using Eulers formula :

$$P = \frac{3Et^3w}{4L^3}$$

Where:
P = Maximum load-bearing capacity
E = Young's modulus of the material
t = Thickness of the plate
w = Width of the plate
L = Length of the plate
In this case, the acrylic sheet is square-shaped, so the width (w) and length (L) are equal.
w = 0.3048 m (width)
L = 0.3048 m (length)
t = 5 mm = 0.005 m (thickness)
E = 3.03 GPa = 3.03×10^9 Pa (Average value taken from figure 34)

Substituting the values into the formula:

$$P = \frac{3x3.03x10^9x0.005^3x0.3048}{4x0.3048^3}$$

$$P \approx 3057.623 \text{ N}$$

Therefore, the maximum load-bearing capacity of the acrylic sheet is approximately 3057.623
Newtons or 312 kgs.

4.2 STRUCTURAL ANALYSIS OF ACRYLIC SHEET:

Plastic, Acrylic (PMMA)

Polymethylmethacrylate (Molding and Extrusion); "Acrylic"

Data compiled by Ansys Granta, incorporating various sources including JAHM and MagWeb.
ANSYS, Inc. provides no warranty for this data.

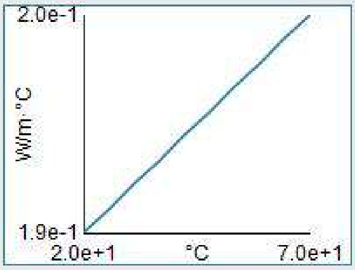
Density	1185	kg/m³
Structural		
Isotropic Elasticity		
Derive from	Young's Modulus and Poisson's Ratio	
Young's Modulus	2.694e+09	Pa
Poisson's Ratio	0.3952	
Bulk Modulus	4.2844e+09	Pa
Shear Modulus	9.6545e+08	Pa
Isotropic Secant Coefficient of Thermal Expansion	0.0001207	1/°C
Tensile Ultimate Strength	6.235e+07	Pa
Tensile Yield Strength	6.235e+07	Pa
Thermal		
Isotropic Thermal Conductivity		
Specific Heat Constant Pressure	1456	J/kg·°C

Figure 26: Properties of Acrylic Sheet on ANSYS Workbench 2022 R1

For a single sheet of acrylic sheet under a weight of 64.74 kg which is the average weight of people in Pakistan [6]:

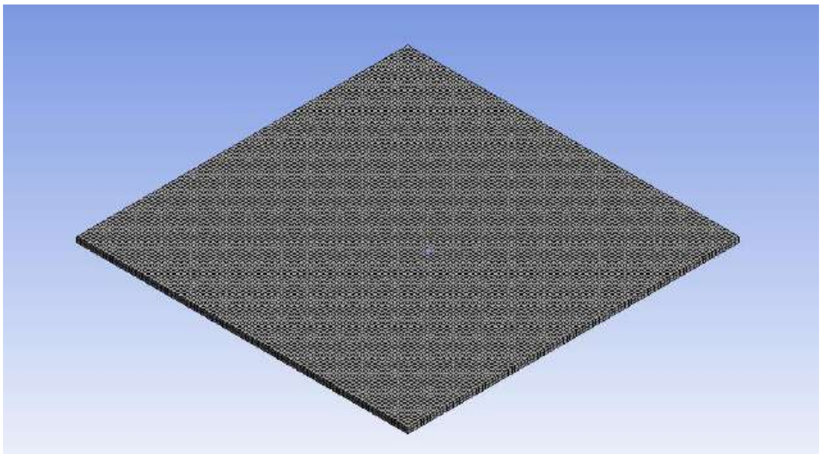


Figure 27: Mesh

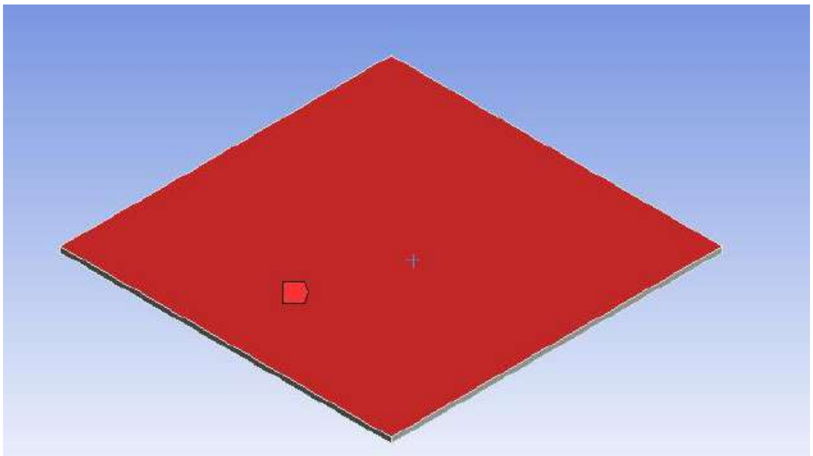


Figure 28: Applied Force

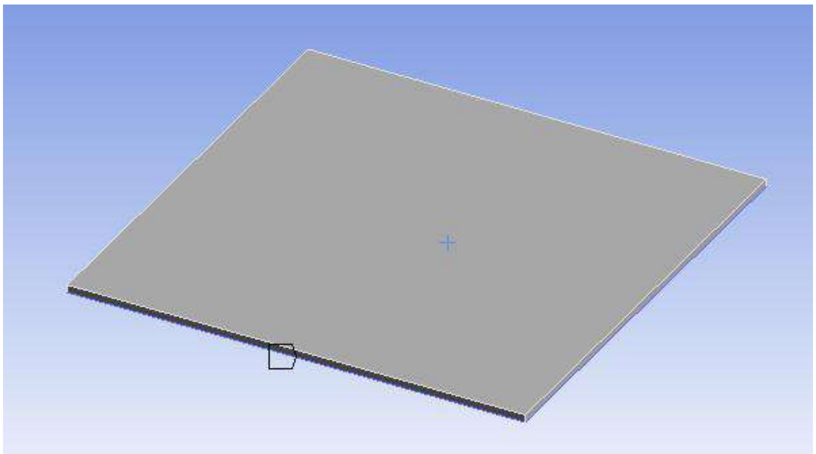


Figure 29: Fixed Support

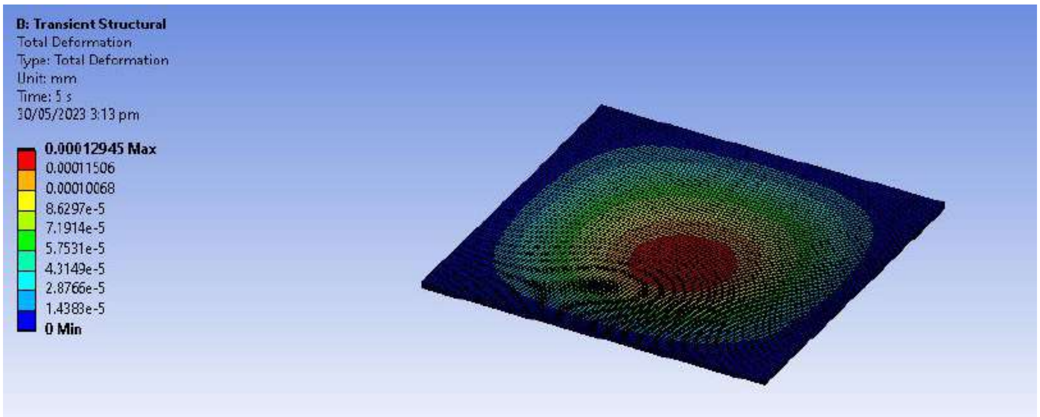
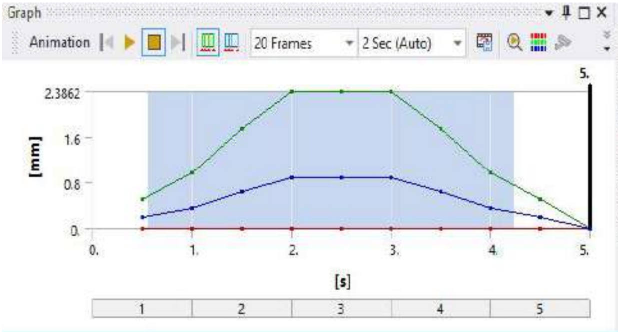


Figure 30: Total Deformation



	Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1	0.5	0.	0.51813	0.1891
2	1.	0.	0.96325	0.35141
3	1.5	0.	1.7551	0.64129
4	2.	0.	2.3862	0.87457
5	2.5	0.	2.3857	0.87442
6	3.	0.	2.3862	0.87458
7	3.5	0.	1.7552	0.64131
8	4.	0.	0.96285	0.35128
9	4.5	0.	0.51912	0.18944
10	5.	0.	1.2945e-004	4.5035e-005

Figure 31: Total Deformation Graph

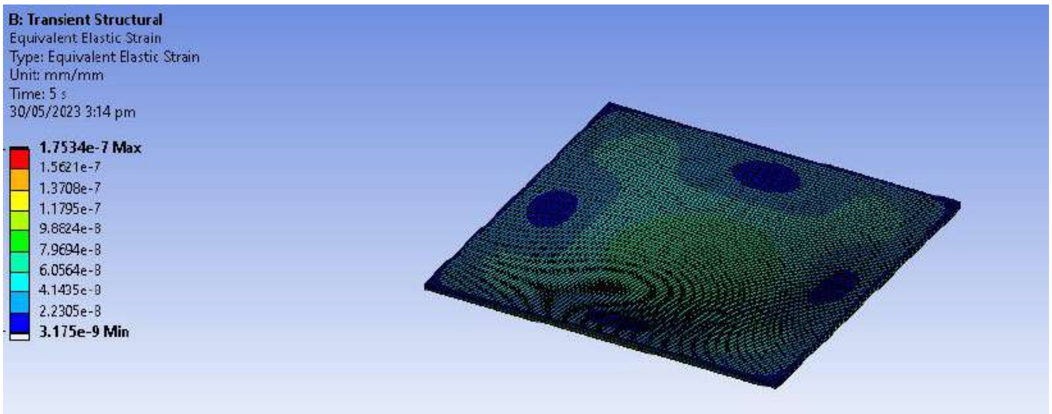
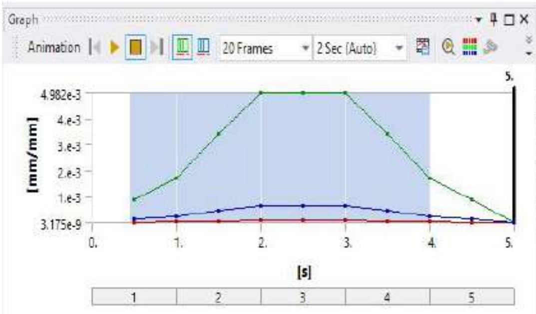


Figure 32: Equivalent Strain



	Time [s]	Minimum [mm/mm]	Maximum [mm/mm]	Average [mm/mm]
1	0.5	1.838e-005	8.8373e-004	1.2994e-004
2	1.	3.2919e-005	1.7257e-003	2.4628e-004
3	1.5	5.662e-005	3.4262e-003	4.6558e-004
4	2.	7.4159e-005	4.9819e-003	6.531e-004
5	2.5	7.4159e-005	4.981e-003	6.5298e-004
6	3.	7.4159e-005	4.982e-003	6.5311e-004
7	3.5	5.662e-005	3.4264e-003	4.656e-004
8	4.	3.2914e-005	1.725e-003	2.4619e-004
9	4.5	1.8399e-005	8.852e-004	1.3017e-004
10	5.	3.175e-009	1.7534e-007	3.0098e-008

Figure 33: Equivalent Strain Graph

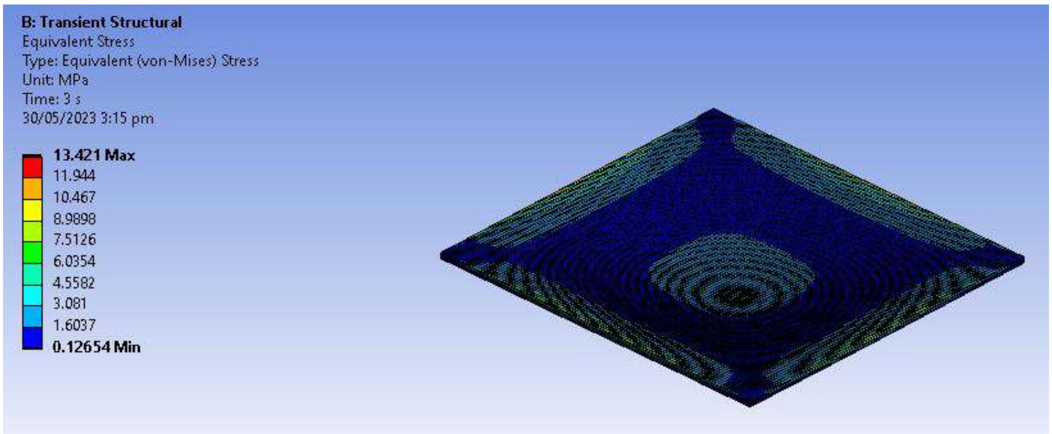
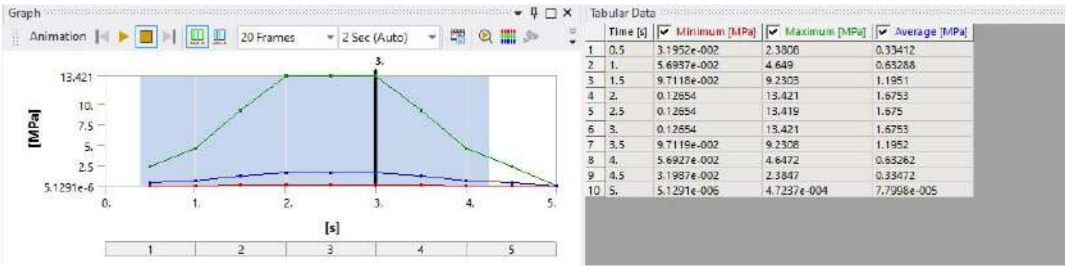


Figure 34: Equivalent Stress



	Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1	0.5	3.1952e-002	2.3808	0.33412
2	1.	5.6937e-002	4.649	0.63288
3	1.5	9.7118e-002	9.2303	1.1951
4	2.	0.12654	13.421	1.6753
5	2.5	0.12654	13.419	1.675
6	3.	0.12654	13.421	1.6753
7	3.5	9.7119e-002	9.2308	1.1952
8	4.	5.6927e-002	4.6472	0.63262
9	4.5	3.1987e-002	2.3847	0.33472
10	5.	5.1291e-006	4.7237e-004	7.7998e-005

Figure 35: Equivalent Stress Graph

4.3 RESULTS:

- The piezoelectric tile generates different voltages at different weights; as the weight increases, so does the voltage produced.
- HEX inverter (High Impedance Amplifier), operates at an input voltage range of 2-6V.
- The input of the HEX inverter is the voltage produced by the piezoelectric tile which is variable.
- When the input voltage is lower than 3.5V , the HEX inverter amplifies it to 9 volts.
- The boost converter requires at least 3.5V to enhance the voltage and that it also needs a lag to function, which the HEX inverter provides.
- The boost converter's increased voltage is adjustable, and it is set at 16V, which is enough to charge our battery.
- Step down Module Practical USB charger Buck Converter has input voltage range of 4.5-40V, whilst the Output voltage is 5V.
- In light of the weight of people, this system will generate 16V and 1.7A for every step, thus a power of 27.2 Watts per footstep.

4.3.1 EXPERIMENTAL RESULTS:

Sr.No.	Voltage Generated at 60 kg (V)	Voltage Generated at 70 kg (V)	Voltage Generated at 80 kg (V)
1	8.4	9.8	11.8
2	8.7	10.2	12.2
3	7.8	10.6	11.5
4	8.1	9.6	10.9
5	7.7	8.4	11.3
Average Voltage Generated (V)	8.14	9.72	11.54

Table 6: Voltage generated per footstep by different weights

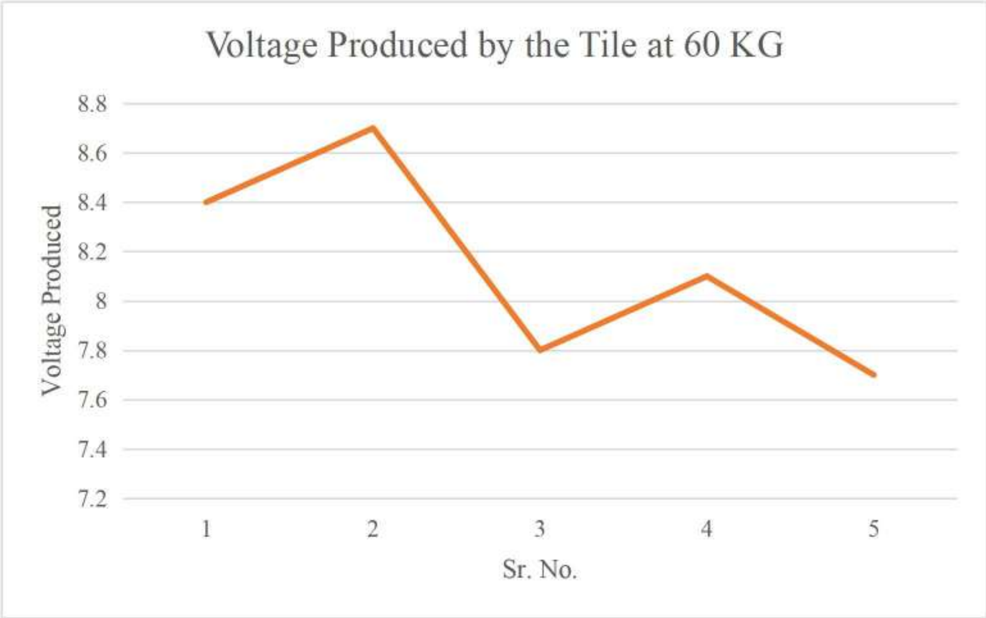


Figure 36: Voltage Produced per footstep at 60 kgs

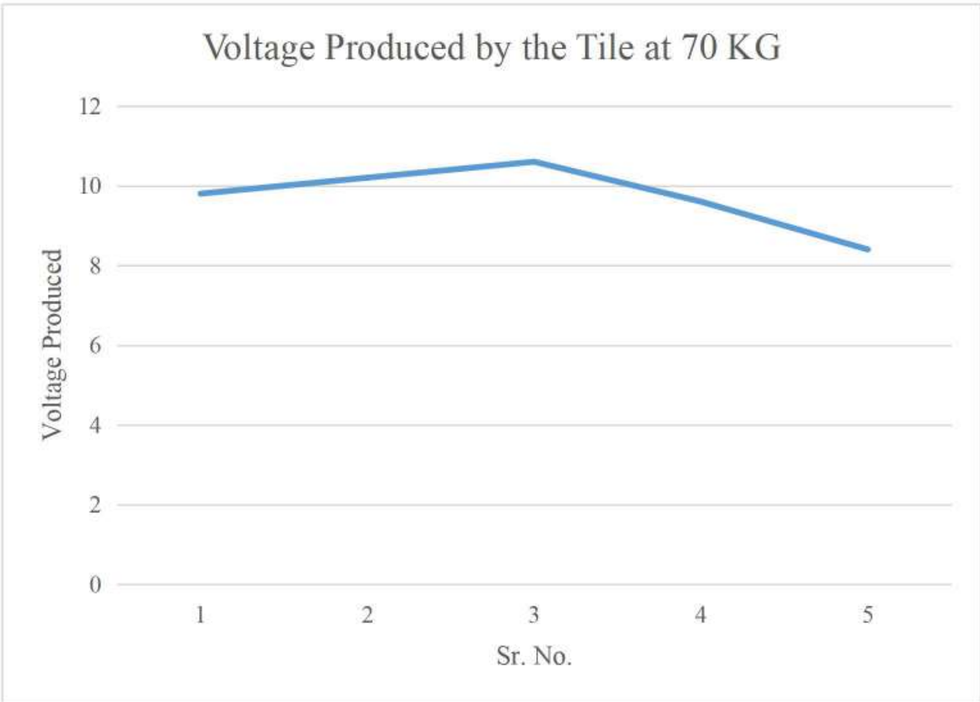


Figure 37: Voltage Produced per footstep at 70 kgs

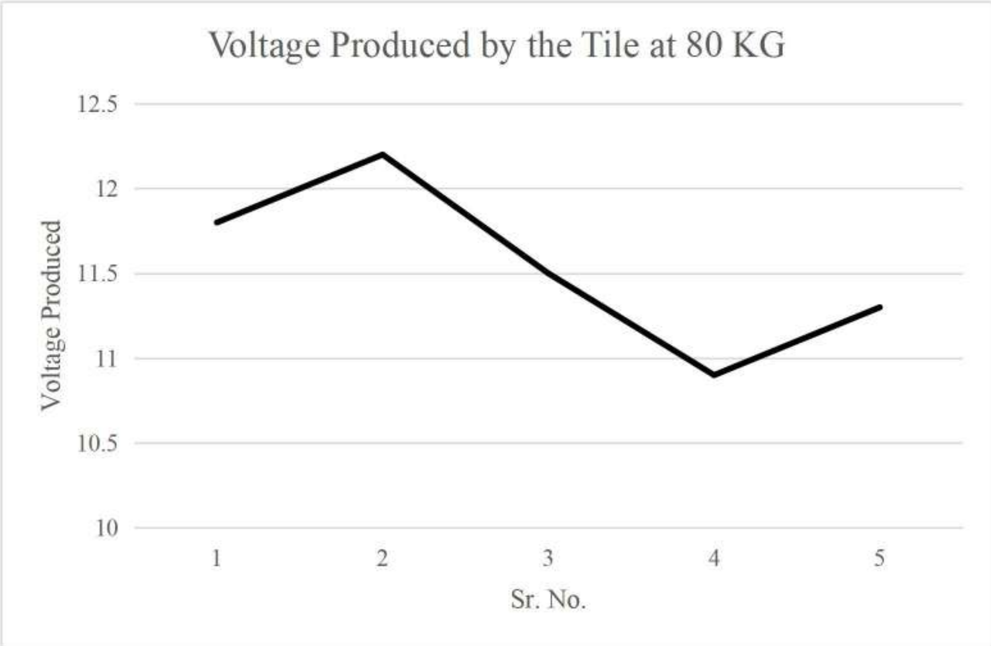


Figure 38: Voltage Produced per footstep at 80 kgs

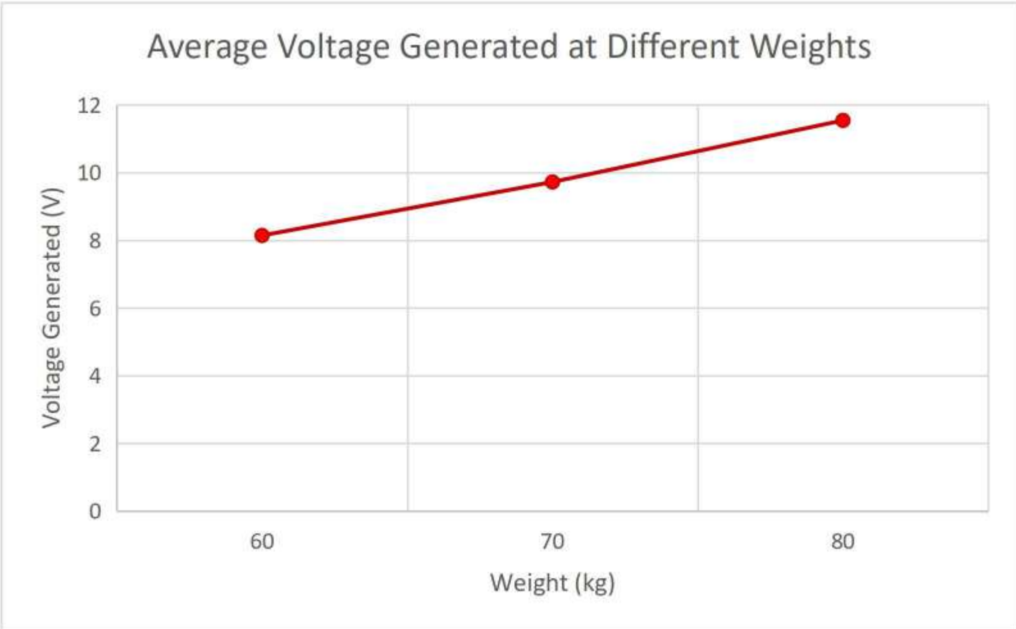


Figure 39: Average voltage generated at different weights.

4.3.2 FINAL PROTOTYPE:

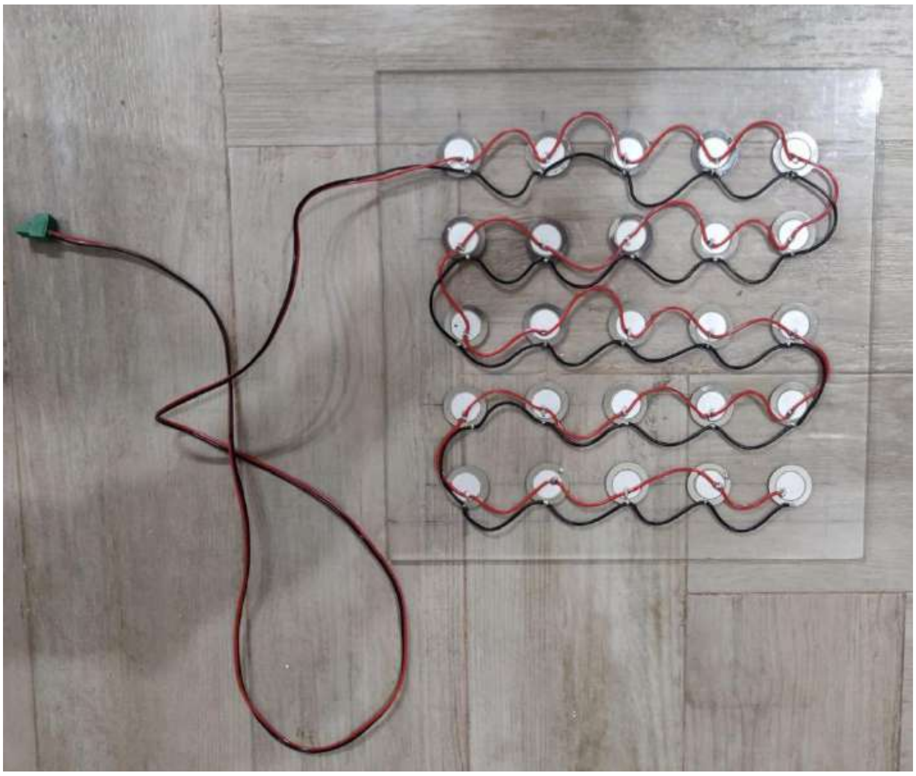


Figure 40: Tile With Sensors

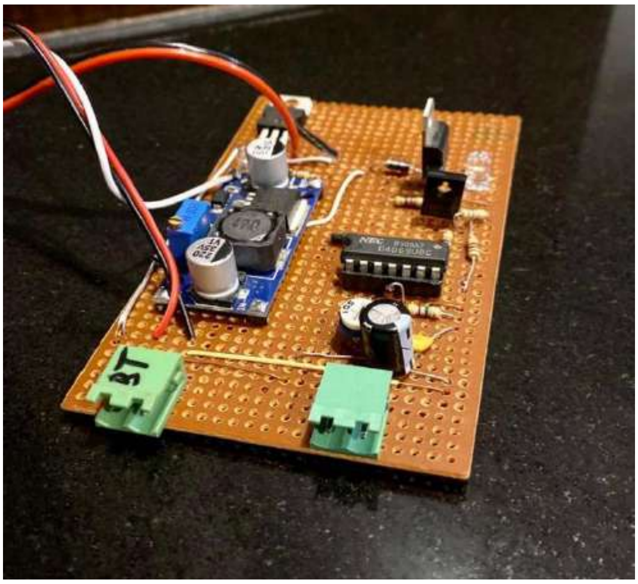


Figure 41: Circuitry

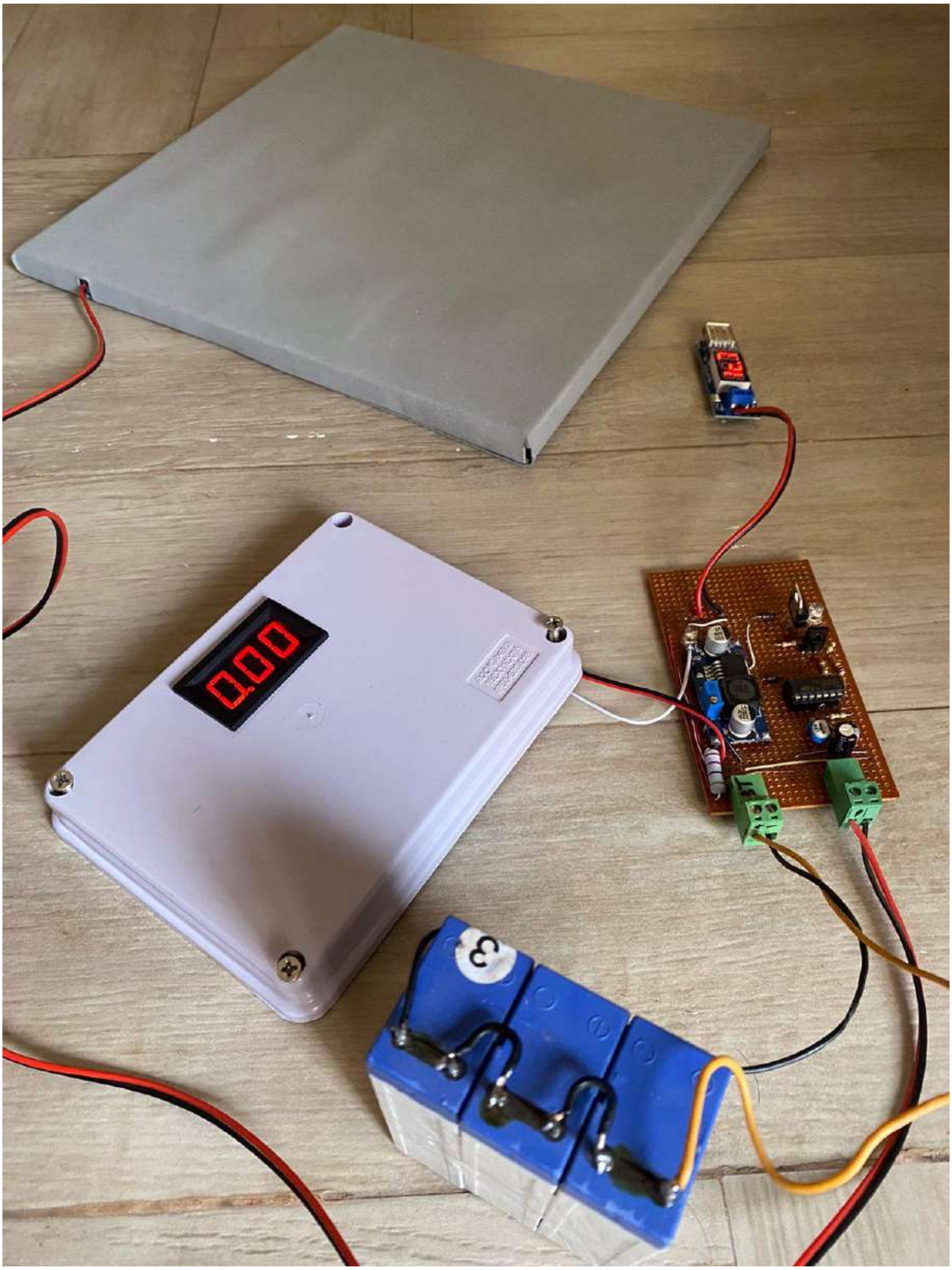


Figure 42: Final Prototype

4.4 COST ANALYSIS:

Table 7: Cost of Equipment

Item Name	**Type**	**No. of Units**	**Per Unit Cost (in Rs)**	**Total (in Rs)**
Piezoelectric Sensors	Equipment	25	15	375
Acrylic Sheets	Equipment	3	500	1500
HEX Inverter	Equipment	1	5000	5000
Boost Converter (XL6009)	Equipment	1	310	310
Battery (12V)	Equipment	1	1300	1300
Foam Mat	Equipment	1	1000	1000
Wire	Equipment	1	500	500
Electrical Box	Equipment	1	250	250
Voltmeter	Equipment	1	300	300
			Total in (Rs)	**10535**

CHAPTER FIVE: DISCUSSION

The data obtained in this study illustrates the viability of employing piezoelectric sensors to create footstep power. To evaluate the system's performance, the power output was measured and analyzed in relation to relevant literature.

When past research was reviewed, it was discovered that various piezoelectric materials and sensor combinations were used, resulting in a wide range of power generation efficiency. Power outputs per step have been reported in studies ranging from a few milliwatts to several watts. The system's efficiency and power production were directly determined by the materials used, sensor design, and electronics.

In our study, we utilized Lead Zirconate Titanate (PZT) as the piezoelectric material for generating footstep power. PZT is distinguished by its strong piezoelectric coefficients and high energy conversion efficiency. PZT outperformed other commonly used materials such as Polyvinylidene Fluoride (PVDF) and Lead Magnesium Niobate-Lead Titanate (PMN-PT) in terms of power generation and stability under footstep stresses. While PVDF was less expensive, it had lower piezoelectric coefficients, resulting in a lesser power output. PMN-PT, on the other hand, had greater piezoelectric coefficients but was more difficult and expensive to manufacture. Overall, PZT proved to be an appropriate and efficient alternative for footstep power generation, balancing performance and cost-effectiveness. We selected a parallel design of piezoelectric sensors since it produced a larger power output. The parallel configuration improved load distribution by effectively utilizing footstep pressure across several sensors and maximizing power generation. The power generated was measured and compared with similar studies using PZT sensors. Our results showed comparable outputs and confirmed the effectiveness of the selected materials, sensor configurations and circuit components.

We conducted a sensitivity analysis to assess the response of the piezoelectric sensors to different footstep pressures. Our results indicated that the power output increased proportionally with increasing footstep pressure. However, we observed diminishing returns when the pressure was relatively low. These findings emphasize the importance of optimizing footstep pressure for maximizing power generation efficiency. Therefore we employed a HEX inverter. The HEX inverter gives our project a big advantage over other projects. The HEX inverter amplifies the voltage signal from the tile to a level sufficient to operate the boost converter even at very light weight, so there is always enough voltage to operate the boost converter. Additionally, the HEX inverter delays the signal to give the boost converter enough time to read the signal and raise the voltage to the required level.

It should be emphasized, however, that the results differed slightly from those of earlier investigations. These variances would be attributable to differences in the experimental setting, changes in sensor configuration, or changes in the applied footstep pressure. Furthermore, environmental conditions such as ambient temperature and humidity may have had an impact on the functioning of the piezoelectric sensors.

One possible explanation for the differences is a discrepancy in measurement methodologies. Previous research may have used various procedures for data collection and processing, resulting in discrepancies in reported results. As a result, when comparing the outcomes of different studies, it is critical to take these considerations into account.

CHAPTER SIX: CONCLUSION AND FUTURE DIRECTION

6.1 CONCLUSION:

Our project successfully demonstrated the feasibility and promise of using piezoelectric sensors to generate footstep power. Our study's findings offer useful insights into the system's efficiency, performance, and optimization.

We discovered that Lead Zirconate Titanate (PZT) is an appropriate and efficient piezoelectric material for generating footstep power. In terms of power output and stability, PZT displayed strong piezoelectric coefficients and great energy conversion efficiency.

By optimizing the sensor arrangement, we discovered that a setup with parallel connections produced the highest power output. This arrangement enabled excellent load distribution and utilization of footstep pressure across numerous sensors, maximizing power generation potential.

Our study demonstrated the significance of footstep pressure in power generation. Higher footstep pressures resulted in increased power output, and the use of a HEX inverter solved the problem that if the foot pressure was lower, the system output would not be reduced.

Our endeavour given the weight of the humans, each step will create 16V and 1.7A, resulting in a power of 27.2 Watts per footstep. Furthermore, the boost converter's adjustable output voltage allows this voltage to be increased up to 35V.

Overall, our effort advances the science of piezoelectric energy harvesting and demonstrates the potential of footstep power generation. The findings verify the efficiency and effectiveness of using PZT as the piezoelectric material and a parallel connection design to maximize power production.

In conclusion, our experiment emphasizes the importance of renewable energy sources and the potential of piezoelectric sensors for footstep power generation. The discoveries aid in the progress of energy harvesting technology and open the way for the generation of sustainable and efficient power from human activities.

6.2 FUTURE DIRECTION:

The following are some potential future directions for this project:

Look into new sensor designs and materials to boost power generating efficiency. Investigate advanced piezoelectric materials or composite constructions with better piezoelectric coefficients, increased durability, and increased sensitivity to footstep pressure. Consider flexible or elastic sensor setups to accommodate varying flooring and walking patterns.

Intelligent energy optimization algorithms that can dynamically alter the power generation process based on real-time footstep characteristics are being developed. Investigate machine learning or artificial intelligence-based ways to optimizing power output, synchronizing footstep frequency with sensor resonance, and intelligently distributing generated power to diverse devices or storage systems.

Investigate synergistic techniques to energy harvesting by integrating piezoelectric sensors with other energy harvesting technologies. Investigate the incorporation of additional harvesting devices, such as solar panels or electromagnetic generators, to capture energy from various sources at the same time. Create hybrid systems that can combine the benefits of many energy collecting technologies for enhanced total power production.

Conduct field trials and real-world deployments to evaluate the performance and feasibility of footstep power production devices in a variety of situations. Work with architectural companies, urban planners, and building developers to incorporate the technology into public places, commercial structures, and high-traffic locations. In real-world settings, collect data on power generating potential, user experiences, and system dependability.

Improve energy storage and management technologies to improve the utilization of generated electricity. Investigate new energy storage technologies such as super capacitors, lithium-ion batteries, and flow batteries, which can store and transfer collected energy effectively. Create intelligent power management systems capable of dynamically allocating and prioritizing the usage of stored energy depending on demand and availability.

Examine the environmental effect of footstep power production systems and look for solutions to improve their sustainability. Assess the life cycle analysis, covering the manufacture, installation, and end-of-life stages, to discover opportunities for improvement. To reduce the overall environmental imprint of the system, use eco-friendly materials, recycling processes, and energy-efficient components.

Conduct user studies and surveys to assess people's acceptability and experience with footstep power production technologies. Examine the user perception, comfort, and safety aspects of walking over piezoelectric surfaces. Incorporate user input to improve the system design, resolving any user issues or restrictions.

Investigate ways for scaling up footstep power production systems for general application. Analyse the economic feasibility, return on investment, and market potential of implementing such technologies in diverse scenarios. Collaborate with industry partners to create cost-effective production methods and business models to facilitate the commercialization of footstep power generating technologies.

By following these future approaches, the research can improve the field of footstep power production employing piezoelectric sensors, enabling sustainable energy harvesting from human activities and contributing to the worldwide shift to renewable energy sources.

Figure 43: Future Direction

REFERENCES

[1] P. Chaturvedi and D. Kumar, "Piezoelectric Energy Harvesting from Vibration Induced Deformation of Floor Tiles Design and development of intelligent control algorithms for frequency regulation in microgrids View project Ph.D Work View project," 2013. [Online]. Available: https://www.researchgate.net/publication/264048738

[2] S. U. Ahmed et al., "Energy Harvesting through Floor Tiles," in 3rd International Conference on Innovative Computing, ICIC 2019, Nov. 2019. doi: 10.1109/ICIC48496.2019.8966706.

[3] A. M. M. Asry, F. Mustafa, S. Y. Sim, M. Ishak, and A. Mohamad, "Study on footstep power generation using piezoelectric tile," Indonesian Journal of Electrical Engineering and Computer Science, vol. 15, no. 2, pp. 593–599, Aug. 2019, doi: 10.11591/ijeecs.v15.i2.pp593-599.

[4] P. B. Abadi, D. Darlis, and M. S. Suraatmadja, "Green energy harvesting from human footsteps," in MATEC Web of Conferences, Sep. 2018, vol. 197. doi: 10.1051/matecconf/201819711015.

[5] D. O. Urroz-Montoya, J. R. Alverto-Suazo, J. R. Garcfa-Cabrera, and C. H. Ortega-Jimenez, "Piezoelectricity: a literature review for power generation support," MATEC Web of Conferences, vol. 293, p. 05004, 2019, doi: 10.1051/matecconf/201929305004.

[6] "https://jpma.org.pk/article-details/8692#:~:text=Mean%20weight%20of%20female%20participants,remained%2064.73%C2%B13.5%20kg."

[7] https://encyclopedia2.thefreedictionary.com/Piezoelectric+Materials

[8] www.matweb.com/search/DataSheet.aspx?MatGUID=a5e93a1f1fff43bcbac5b6ca51b8981f

[9] https://www.ultrasonicadvisors.com/comsol-simulation-of-the-direct-piezoelectric-effect

[10] https://www.electronics-tutorials.ws/filter/filter_1.html

L1F19BSME0072 - MUHAMMAD TALHA KHAN

ORIGINALITY REPORT

15%	9%	9%	8%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Denis O. Urroz-Montoya, Jeffrey R. Alverto-Suazo, Julio R. Garcfa-Cabrera, Cesar H Ortega-Jimenez. "Piezoelectricity: a literature review for power generation support", MATEC Web of Conferences, 2019 Publication	2%
2	Syed Umaid Ahmed, Arbaz Sabir, Talha Ashraf, Muhammad Ali Haider, Farha Perveen, Zafeer Farooqui, Riaz Uddin. "Energy Harvesting through Floor Tiles", 2019 International Conference on Innovative Computing (ICIC), 2019 Publication	1%
3	mafiadoc.com Internet Source	1%
4	www.me.mtu.edu Internet Source	1%
5	ipv6.freelists.org Internet Source	1%
6	components.monofindia.com Internet Source	1%

7	Submitted to Ajman University of Science and Technology Student Paper	1 %
8	www.matec-conferences.org Internet Source	1 %
9	Submitted to Georgia Southern University Student Paper	1 %
10	Submitted to Pamantasan ng Lungsod ng Valenzuela Student Paper	<1 %
11	Anis Maisarah Mohd Asry, Farahiyah Mustafa, Sy Yi Sim, Maizul Ishak, Aznizam Mohamad. "Study on footstep power generation using piezoelectric tile", Indonesian Journal of Electrical Engineering and Computer Science, 2019 Publication	<1 %
12	studenthub.city.ac.uk Internet Source	<1 %
13	Submitted to University of Witwatersrand Student Paper	<1 %
14	Putri Berlian Abadi, Denny Darlis, Mas Sarwoko Suraatmadja. "Green energy harvesting from human footsteps", MATEC Web of Conferences, 2018 Publication	<1 %

15	discovery.ucl.ac.uk Internet Source	<1 %
16	etda.libraries.psu.edu Internet Source	<1 %
17	Submitted to University of Strathclyde Student Paper	<1 %
18	Submitted to Birla Institute of Technology and Science Pilani Student Paper	<1 %
19	Submitted to University of Hong Kong Student Paper	<1 %
20	owiki.org Internet Source	<1 %
21	www.mressaywriter.com Internet Source	<1 %
22	www.belden.com Internet Source	<1 %
23	www.solutions-summit.org Internet Source	<1 %
24	Corina Covaci, Aurel Gontean. "Energy harvesting with piezoelectric materials for IoT – Review", ITM Web of Conferences, 2019 Publication	<1 %
25	P.Hema Chandu, A.Venkata Vinay, K.N.D. Jagadeesh, S. S. V. Kanaka Raju, V.G.Mani	<1 %

Sharan. "Foot Step Micro-Level Power Generation", 2022 3rd International Conference on Communication, Computing and Industry 4.0 (C2I4), 2022
Publication

26	Submitted to University of Aberdeen Student Paper	<1%
27	www.knowledgeboat.com Internet Source	<1%
28	theses.lib.polyu.edu.hk Internet Source	<1%
29	www.frontiersin.org Internet Source	<1%
30	www.coursehero.com Internet Source	<1%
31	Submitted to De Montfort University Student Paper	<1%
32	Arnab, Md. Mostaqim Billah, Shah Md. Rahmot Ullah, Md. Ashraful Alam, Raton Kumar Nondy, A S M Forhadul Alam, and Anik Paul Mishu. "Generation of electrical energy using piezoelectric material from train wheels: Bangladesh perspective", 2014 9th International Forum on Strategic Technology (IFOST), 2014. Publication	<1%

33	Gabriele Bocchetta, Giorgia Fiori, Salvatore Andrea Sciuto, Andrea Scorza. "Performance of Smart Materials-Based Instrumentation for Force Measurements in Biomedical Applications: A Methodological Review", Actuators, 2023 Publication	<1 %
34	Poyyamozhi Mukilan, Murugesan Balasubramanian, Rajamanickam Narayanamoorthi, Perumal Supraja, Chidambaranathan Velan. "Integrated solar PV and piezoelectric based torched fly ash tiles for smart building applications with machine learning forecasting", Solar Energy, 2023 Publication	<1 %
35	elar.tsatu.edu.ua Internet Source	<1 %
36	export.arxiv.org Internet Source	<1 %
37	Dhananjay Kumar, Pradyumn Chaturvedi, Nupur Jejurikar. "Piezoelectric energy harvester design and power conditioning", 2014 IEEE Students' Conference on Electrical, Electronics and Computer Science, 2014 Publication	<1 %
38	infoscience.epfl.ch Internet Source	

<1%

Exclude quotes	Off	Exclude matches	Off
Exclude bibliography	On		