Feasibility Study of a Piezoelectric Footstep Power Generator for Smart University Campus

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***Abstract*—In the emerging landscape of smart urban development, the integration of sustainable and intelligent technologies is peculiar for shaping the future of education environments. Universities are increasingly transforming into smart campuses, through innovation and harnessing data-driven and eco-friendly solutions to enhance the educational milieu and operational efficiency. Within this smart campus vision, piezoelectricity emerges as a groundbreaking avenue for renewable energy harvesting. This paper presents a thorough investigation into the deployment of piezoelectric energy harvesting systems in a university setting, where the continuous people foot traffic offers an untapped resource for energy production. By embedding piezoelectric materials within the walkways that pulse with academic life, the study showcases how a campus can transform pedestrian activity into electrical power, feeding back intro powering lines, lighting academic pavements, and fostering a self-sustaining energy ecosystem. Our research determined an estimate of 4.3 Watts of electric power that can be generated by a single individual. Indicating the viability of such systems in contributing to the smart campus infrastructure and innovative ways to generate electric energy.**

***Index Terms*—Smart Campus, Piezoelectric Sensor, Electric Power Generation, Footstep generation.**

I. Introduction

IN the midst of rapidly urbanizing cities and an escalating demand for sustainable solutions, the concept of smart cities has emerged as a cornerstone in the narrative of contemporary urban development. Far from being merely a collection of technological infrastructures, smart cities represent a holistic ecosystem that seamlessly integrates technology, governance, and community engagement to champion sustainable urban growth [1]. A fundamental component of this sustainability is the emphasis on optimizing energy consumption, enhancing waste management practices, and improving transportation systems. This approach highlights the advantages of incorporating renewable, non-exotic energy sources into the urban fabric [2]. The adoption of such energy solutions within urban infrastructure not only confronts immediate environmental and sustainability challenges head-on but also lays the foundation for creating urban spaces that are resilient, efficient, and conducive to the well-being of future generations.

Furthermore, extensive research efforts have been and continue to be devoted to exploring the potential of piezoelectricity, especially in the realm of footstep power generation [6] [19]. This innovative approach leverages a noise-free power generator that capitalizes on the mechanical energy exerted by human footsteps (e.g., human kinetic energy) on piezoelectric sensors [3] [6]. When individuals walk or exert pressure on surfaces equipped with piezoelectric materials, these materials undergo slight deformations. This, in turn, generates voltage through the piezoelectric effect, allowing the captured energy to be either stored for later use or immediately utilized to power devices with low energy consumption, such as street lighting or informational signage [16] [21] [7] [17]. Particularly, the application of piezoelectric technology in various public spaces within a smart campus setting can significantly enhance energy efficiency and bolster sustainability initiatives, especially considering that it is carbon-free energy source [4] [6] [8].

This paper aims to shed light on how piezoelectric footstep power generation systems present a viable and sustainable method for harnessing energy from daily activities, as an illustration of a smart campus. Section II reviews some theory regarding piezo sensors and materials used to build the sensor. Section II introduces our proposed system, detailing the integration of this technology within our university campus to embrace and advance the smart campus concept. Section III discusses our experimental results and findings. Concluding, we offer final thoughts on the efficacy of the system and propose directions for future innovation.

II. Theoretical Background

The core principle behind piezoelectric footstep power generation systems lies in the piezoelectric effect, which is the ability of certain materials to generate an electric charge in response to applied mechanical stress. The electricity generation mechanism is simplified in Figure 1. This property is harnessed to convert the energy from footsteps into electrical energy. When these materials are subjected to mechanical stress, they produce an electric charge across certain planes of the crystal, a response known as the direct piezoelectric effect that can be expressed in the tensor form as:

$$\mathbf{D_i} = \mathbf{d_{ijk}} \cdot \sigma_{\mathbf{jk}} \tag{1}$$

where D is the electric displacement (charge density), d is the piezoelectric constant (material-specific coefficient), and σ is the mechanical stress applied to the material.

Conversely, the application of an electric field can induce mechanical deformation in the crystal, known as the reverse piezoelectric effect, given as:

$$\mathbf{S_{ij}} = \mathbf{d_{ijk}} \cdot \mathbf{E_k} \tag{2}$$

where S is the strain (deformation) experienced by the material, d is the piezoelectric constant, and E is the electric field applied to the material.

The subscripts *i*,*j*, and *k* represent the respective axes in three-dimensional space, and d_{ijk} is the piezoelectric tensor that varies with the symmetry of the crystal and the direction of the applied electric field or mechanical stress.

In the industry, piezoelectric materials are broadly classified into two categories:

- **Naturally Occuring Crysrals**: such as quartz, are prized for their stability and are commonly used in frequency control and timing applications. Due to their low piezoelectric coefficients d_{ijk}, their energy conversion efficiency is rather limited.
- **Synthetic Materials**: Synthetic materials, including piezoceramics like lead zirconate titanate (PZT), have higher piezoelectric constants and are widely used due to their high sensitivity and ease of production in various shapes and sizes. Many materials can be used such as PbTiO3, PbZro3, PVDF. However, PZT, in particular, is favored in applications requiring significant mechanical force or high-voltage output due to its robustness and versatility [13], and will be used in our design of the footstep power generator system. The force-voltage characteristics vary from one material to another [10].

In our case we use the PZT as our piezoelectric crystal and study the response of the material to a range of applied stress values with a small prototype. Then we use these characteristics to build a piezopath in the university campus academic area. To justify our choice, firstly, PZTs' high efficiency and straightforward implementation align well with the energy harvesting goals in an academic environment, leveraging both the direct and reverse piezoelectric effects for efficient energy conversion from pedestrian movement [20]. Secondly, the material's robustness and high piezoelectric constant make it an optimal choice for producing substantial energy outputs necessary for powering campus infrastructures. Economic analysis [17] the cost-effectiveness and economic viability of simple transducers, presenting a cost-efficient solution with a quick return on investment.

III. Methodology

In this section, we delineate the methodologies adopted in our study, segmented into two principal components. Initially, our objective is to discern the correlation between mechanical stress applied to piezoelectric materials and the resultant voltage generation capable of energizing electrical loads. This correlation was explored via a simulation constructed in Tinkercad. The simulation facilitated an analysis whereby the relationship between the exerted weight and the generated voltage was graphically represented, as indicated in Figure 2.

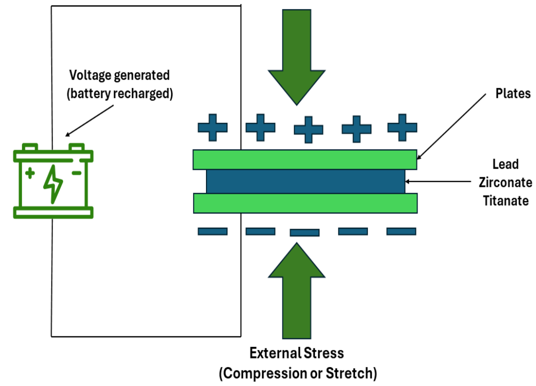

Fig. 1. Schematic of Piezoelectric Energy Harvesting Process from Mechanical Stress to Electrical Charge Accumulation.

Subsequently, our investigation is concerned with the practical feasibility of deploying a piezoelectric energy harvesting system within bustling academic corridors, aiming to autonomously power essential building infrastructures for a smart academic area. This segment of our study is rooted in the strategic placement of piezoelectric systems across locales that witness a constant flux of student activity, effectively turning these high-traffic zones into potent sources of renewable energy. The intricacies of this process are outlined in Figure 5, where we harness the mechanical energy emanating from pedestrian footfall. This setup ingeniously converts the routine act of walking into a dynamic energy reservoir, channeling the generated voltage towards the electrification of pavements and the provision of charging ports strategically located within the university's corridors. By capitalizing on the piezoelectric principle, we aim to not only illuminate walkways for enhanced safety during low-light conditions but also facilitate the convenience of on-the-go charging facilities, thereby embedding a layer of sustainability and technological innovation into the campus infrastructure. This exploration is an attempt to establish the symbiotic relationship between human mobility and energy generation, positing the piezoelectric system as a cornerstone for smart, energy-efficient campus designs.

A. The analysis of a the piezoelectric system

The piezoelectric sensor can be effectively modeled with a force sensor that will allow the modulation of the applied force [9]. Figure 4 shows the piezosensor used in our design. This adaptation allows for the quantification of force through the illumination intensity of LEDs.The generated voltage from the piezoelectric sensor is fed into one of the Arduino's analog input pins. The Arduino reads the voltage level and converts it from an analog signal to a digital value that can

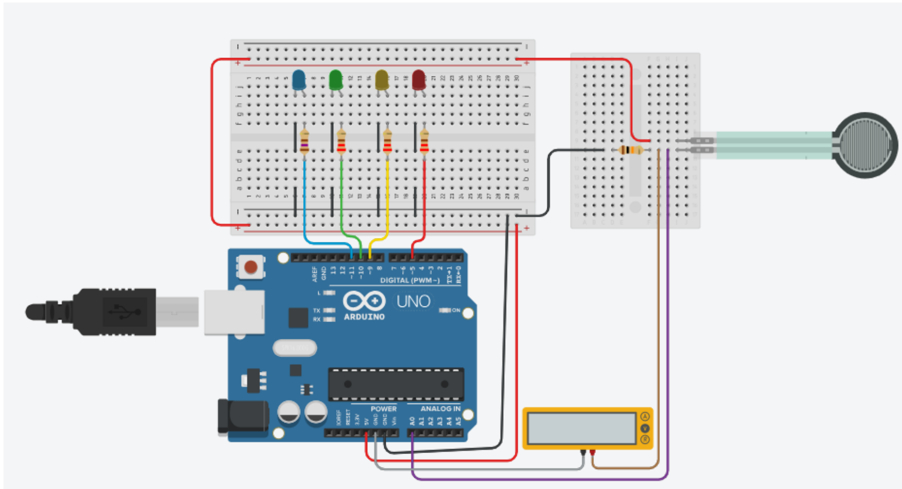

Fig. 2. Visual Representation of Force-to-Voltage Conversion Simulation via Tinkercad.

Fig. 3. Satellite view of the university campus showing the implementation of the piezo footstep power generation system in the academic area (shown in black lines).

Algorithm 1 Piezoelectric Sensor Reading and LED Response Algorithm Pseudo-code

```
blueled ← 11
greenled ← 10
yellowled ← 9
redled ← 5
sensorpin ← A0
procedure SETUP
pinMode(blueled, OUTPUT)
pinMode(greenled, OUTPUT)
pinMode(yellowled, OUTPUT)
pinMode(redled, OUTPUT)
pinMode(sensorpin, INPUT)
Serial.begin(9600)
end procedure
while true do
sensor ← analogRead(A0)
Serial.println(sensor)
    if sensor > 0 then
tmap ← map(0, 749, 0, 1023, sensor)
        if sensor > 749 then
digitalWrite(blueled, HIGH)
        else
analogWrite(blueled, tmap)
        end if
    else
digitalWrite(blueled, LOW)
    end if
    if sensor > 749 then
tmap ← map(749, 835, 0, 1023, sensor)
        if sensor > 835 then
digitalWrite(greenled, HIGH)
        else
analogWrite(greenled, tmap)
        end if
    else
digitalWrite(greenled, LOW)
    end if
    if sensor > 835 then
tmap ← map(835, 874, 0, 1023, sensor)
        if sensor > 874 then
digitalWrite(yellowled, HIGH)
        else
analogWrite(yellowled, tmap)
        end if
    else
digitalWrite(yellowled, LOW)
    end if
    if sensor > 874 then
tmap ← map(874, 899, 0, 1023, sensor)
        if sensor > 899 then
digitalWrite(redled, HIGH)
        else
analogWrite(redled, tmap)
        end if
    else
digitalWrite(redled, LOW)
    end if
```

Fig. 4. The piezo sensor used to generate electric energy.

be processed following the algorithm shown in Algorithm 1. The overarching system, depicted in Figure 2, incorporates an array of carefully selected components that comprises:

- **Arduino Uno** Rev3 that is based on ATmega328P serves as the central processing unit for the simulation, interpreting the voltage signals from the piezoelectric sensor and managing the output to the LEDs. The Arduino reads the voltage level and converts it from an analog signal to a digital value.
- **Light Emitting Diodes (LEDs)** : An assorted array of five LEDs of distinct colors has been incorporated, each linked to its own digital pin on the Arduino (pins 5, 6, 9, 10, and 11) through a precise current-limiting resistor. This configuration is designed to allow each LED to symbolize varying thresholds of force exerted upon the piezoelectric sensor. The color spectrum ranges from a calm blue to an urgent red, each representing a progressive increase in the force applied. Resistors are used to limit the amount of current passing through the LEDs to prevent any potential damage.
- **Force Sensor** interfaced seamlessly with the analog pin A0 on the Arduino, the force sensor is the primary component responsible for the detection of mechanical pressure. The output of this sensor is directly correlated with the applied force and is manifested through the voltage signal that the Arduino reads. The intensity and quantity of the emitted LED light serve as a proxy for the magnitude of force detected by the sensor, providing a visual and intuitive gauge of the energy harvesting system's efficacy.

B. The design of a footstep power generation: Academic area as example

In the second part of this paper, we examine the mechanism through which pedestrian traffic-induced mechanical stress on flooring embedded with piezoelectric materials leads to the generation of electrical energy. The core principle hinges on the material deformation under stress, facilitating electric charge generation, which is subsequently converted into usable electrical power. In our system, we implement this design in the university academic corridors where student activity is versatile. A satellite view of the integration of the piezosensors on academic pavements is shown in Figure 3. This dynamic process, underpinned by rigorous empirical analyses such as those conducted by [14] [11], points to the optimal efficiency of parallel configurations of piezoelectric materials over series configurations. Specifically, while series configurations might amplify voltage outputs, they fall short in proportionally boosting current density—a critical factor for energy harvesting systems aimed at practical utility. Consequently, our design leverages a parallel interconnection strategy to maximize both voltage and current output, thereby optimizing the energy harvesting potential.

For the quantification of the total electric power generated, our methodology incorporates a comprehensive calculation framework. From Figure 3, we can infer the spatial dimensions of the academic hallways, measuring approximately 241.68 meters in length and 4.63 meters in width. Assuming an average pedestrian weight of 60 Kilograms, as suggested by [16], we extrapolate the force exerted per step. Coupled with the deployment of a reasonable density of 250 piezo sensors per square meter [16], this approach allows for a granular analysis of power generation potential across the hallway's expanse. Given the inherent limitations of piezoelectric materials concerning force saturation, our calculations are predicated on achieving a maximum voltage output corresponding to the saturated force threshold of our system. These results will be shown in details as empirical results of our system shown in Figure 2. This decision is further substantiated by the assumption of two steps per second per individual, a conservative estimate reflective of the high foot traffic typical of crowded academic settings as highlighted in [16]. In our analysis, we will also perform a Finite Element Method to examine the response of the piezosensor to the external stress and hence evaluate the realiability and viability of the system. Finally, we should be concerned with the static capacitance of the PZT that we are using. According to [18], the relative dielectric constant (d_r) of the PZT films is mentioned to be in the range of 1000 to 1100. In our design, we use the sensor shown in Figure 4, known for a diameter of 55mm and a thickness of 1.25mm. We can compute the estimate capacitance given by:

$$\mathbf{C} = \epsilon_0 \mathbf{d_r} \frac{\mathbf{A}}{\mathbf{d}} \tag{3}$$

Where ϵ_0 is the is the vacuum permittivity and $\mathbf{A}$ is the area of the electrode in contact with the PZT layer in square meters, and $\mathbf{d}$ is the thickness of the PZT layer in meters.

Substituting the given values:

$$C = 8.854 \times 10^{-12} \times 1050 \times \frac{0.002375}{0.00125} C \approx 17.665nF$$

Therefore, with a thickness of 1.25 mm, the estimated capacitance of the PZT film is approximately 17.665 nF (nanofarads).

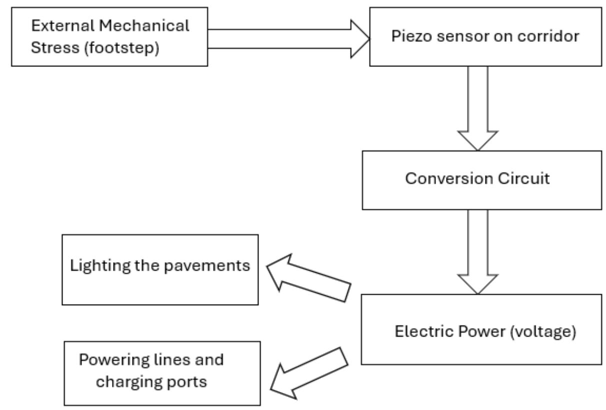

Fig. 5. The piezosensor used to generate electric energy.

To estimate the average total electric energy generated, we simply use

$$\zeta = \frac{\mathbf{1}}{\mathbf{2}} \mathbf{C} \mathbf{V}^{\mathbf{2}} \tag{4}$$

And to get the average total power, we use

$$\mathbf{P} = \frac{\mathbf{dE}}{\mathbf{dt}} \tag{5}$$

The cost analysis, factoring in the unit price of a single PZT piezosensor at approximately 3.5 dollars [17], underlines the economic viability of our proposed energy harvesting solution. Table I synthesizes these calculated metrics area coverage, sensor deployment density, force exertion per pedestrian, and sensor cost— used in to derive the total electric power generated.

Lastly, we compute the levelized cost of energy as a metric to measure the average net present cost of electricity generation of the piezo plant over a span of 5 years. The formula is given by:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} (6)$$

where:

- I_t = Investment expenditures in the year t
- M_t = Operations and maintenance expenditures in the year t
- F_t = Fuel expenditures in the year t
- E_t = Electricity generation in the year t
- r = Discount rate
- n = Life of the system

From the referenced study [15], we adopt a value of M_t to be 85 USD. As the piezo system does not incur fuel expenditures, we appropriately set this component to zero. Typically, discount rates for similar projects can vary between 5% and 10% [5], we take the average which 7.5% mirroring both the anticipated rate of return and the investment's risk profile.

TABLE I
IMPORTANT DATA REGARDING THE ACADEMIC PAVEMENT AND COSTS

Parameter	Data
Total Area (**A**)	(241.68 x 4.63) m^2
Number of steps per second (**n**)	2 steps per second
Number of Piezosensors/m^2 (**N**)	250 piezosensors
Avg. force exerted by one student (**F**)	60x9.81 Newtons
Estimated static Capacitance (**C**)	17.66 nF
Maximum voltage generated by each step (**V**)	5V
Average cost of a single piezosensor ($\boldsymbol{C_p}$)	3.5 USD
Total number of students and faculty using the pavement during business days ($\boldsymbol{N_b}$)	1000-1500 individuals
Total number of students and faculty using the pavement during the weekend ($\boldsymbol{N_w}$)	100-150 individuals

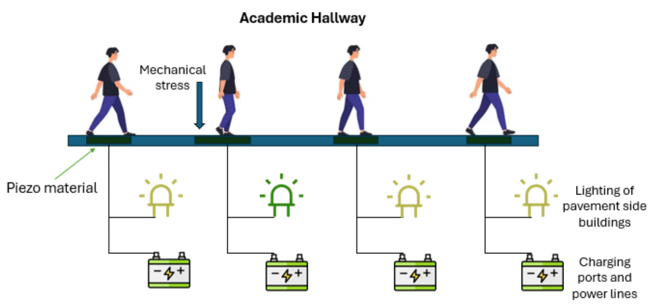

Fig. 6. Schematic of the implementation of the footstep generation system in the academic corridors of the university where student crowdedness is very common.

Through the engagement of individuals walking over the piezoelectric sensors, kinetic energy is transmuted into electrical energy, subsequently stored within a battery to power lines and charging ports. Additionally, a fraction of that energy will be used for the lighting of the pavement side buildings. A schematic of the system is shown in Figure 6, which shows an individual walking in the academic hallway while exerting mechanical stress on the piezosensor, inducing the necessary voltage to power the battery and the bulbs, similarly to our previous prototype. This research applies the outcomes derived from the initial experimental phase to an array of piezoelectric sensors spread across a one-square-meter section within the university's academic corridors, identified as areas of high pedestrian activity.

An estimation of the student foot traffic during business days within these corridors is summarized in Table I, indicating the potential energy harvesting capabilities of piezoelectric sensors in such environments.

IV. RESULTS AND DISCUSSION

A. The Force-Voltage characteristics

The empirical data allows us to record the values of the voltage produced with respect to the applied force. Upon collection, this analog data stream is converted into a digital format comprehensible to the Arduino, which subsequently triggers the illumination of LEDs in direct proportion to the force's magnitude. The resulting plot is shown in Figure 8, which displays the force-voltage characteristics of the simulated system. 8 shows the relationship between the voltage generated by a piezoelectric material and the mechanical force applied to it. The x-axis represents the applied force in newtons (N), and the y-axis represents the generated voltage in volts (V).

From the graph, we observe that the voltage increases rapidly with a small increase in applied force at the beginning, indicating a highly sensitive response of the piezoelectric material to initial forces. As the force increases, the voltage continues to rise but at a decreasing rate, exhibiting a saturation effect. It appears to approach a plateau near 5 volts, suggesting that there is a maximum voltage that the piezoelectric material can generate under the given conditions. Our setup allows the saturation of the the voltage generated to a specific value that we specify through the Arduino. We can leverage this to control the total amount energy that would be generated by the piezo material. This will prove to be useful as it will simplify the calculations of the total energy generated by the piezo and the subsequent cost analysis. Additionally, we attempted to plot the fluctuations of the induced voltage with respect to resistance load variation. The plot is shown in Figure 9. The plot shows that while there are minor variations in voltage values, the overall trend does not exhibit any significant spikes or drops across the range of resistance values. This reflected stability can be inferred from the relatively smooth and consistent path of the line graph, with the voltages remaining within a narrow band around the 4.5V mark. It is also an indicative of the system's ability to provide consistent energy output.

In addition, the Finite Element Method (FEM) analysis displayed in Figure 7 indicates the von Mises stress distribution in a piezoelectric disk of 55mm diameter and 1.5mm thickness under a compressive force equivalent to 60kg, or approximately 600N. The color-coded stress diagram, with values ranging from 1.16e+05 to 2.28e+05 Pascals, suggests that the highest stress concentration occurs at the perimeter of the disk, shown in red, while the lowest stress appears at the center, as indicated by the blue color. The symmetrical pattern of the stress gradient is indicative of an evenly applied force across the surface of the disk. Such a distribution is expected when a uniform load is applied perpendicular to the disk. The smooth transition of colors from the edge towards the center reflects a predictable and gradual change in stress, with no abrupt stress concentrations that could lead to material failure. Ensuring that the maximum stress does not exceed the material's yield strength is critical to avoid permanent deformation or fracturing of the piezoelectric disk during operation. This analysis is a vital step in validating the design and integrity of the piezoelectric component under expected load conditions.

It is also essential to note that the von Mises stress distribution indicated by the FEM analysis applied to the PZT, as shown in Figure 7, is relevant when considering pedestrian comfort and safety in applications where the piezoelectric disk is used as a part of an energy-harvesting floor system. The symmetrical and smooth stress profile, with a maximum at the edge and a minimum at the center, suggests that the piezo disk can withstand the applied force without abrupt stress peaks that could lead to material failure. This is critical for pedestrian comfort, as it implies that the disk will not crack or break under the weight of a person walking over it, thereby preventing potential tripping hazards or sharp edges that could cause injury. The fact that the maximum stress levels are well within the material's limits ensures longevity and durability, meaning that the piezoelectric flooring system can maintain its structural integrity over time, even with continuous use. This reliability contributes to a safe walking environment, as there is less risk of sudden failure that could compromise the structural stability of the floor.

B. Technical feasibility of the piezoelectric system

If we assume a total saturation of 5V obtained in the previous section for each step for each student, we can calculate the total amount of electricity generated, also by using formula 4 and 5.

We calculate the total area in square meters (m^2):

$$\text{Total Area} = 241.68 \times 4.63 \tag{7}$$

Subsequently , we determine the total number of piezosensors based on the area and the number of piezosensors per m^2:

$$\text{Total Piezosensors} = \text{Total Area} \times 2 \tag{8}$$

We also estimate the total voltage generated per second by assuming each piezosensor generates a maximum voltage of 5V for each step and considering two steps per second:

$$\text{Total Voltage Per Second} = \text{Total Piezosensors} \times 5V \times 2 \tag{9}$$

Finally, we calculate the estimated total electric power per individual using:

$$\text{Total Power} = \frac{1}{2} \times (\text{Total Voltage Per Second})^2 \times \text{Capacitance} \tag{10}$$

Given the provided formulas, we plug in the numbers obtained from Table I

- Total Area = $241.68 \times 4.63 = 1119.59m^2$
- Total Piezosensors = $1119.59 \times 2 \approx 2240$ piezosensors
- Total Voltage Per Second =$2240 \times 5V \times 2 \approx 22400V$
- Total Power Per Individual = $\frac{1}{2} \times 22400^2 \times 17.66 \times 10^-9 \approx 4.43W$

This is a significant amount of power when considering the aggregate contribution of all students and faculty members moving across the piezoelectrically equipped areas throughout a day. To provide a more comprehensive understanding of the potential impact of this technology, Figure 10 plots the total power generated per day, contingent upon the total number of individuals which we randomly selected to be in the range of 1000 to 1500 individuals on business days, and 100 to 150 individuals on the weekend. This illustrate the scalability of piezoelectric energy harvesting in a bustling academic environment, highlighting its potential to contribute significantly to the campus's energy sustainability efforts.

The piezoelectric footstep power generation system, by converting pedestrian traffic into electrical energy, can serve as a foundational energy source that complements and powers other smart systems. For instance, the harvested energy could be directly utilized to support smart lighting systems, where lights adjust dynamically based on real-time occupancy or natural light level [1].

C. Economic feasibility of the piezoelectric system

Drawing from the data presented in Table I, the average piezoelectric sensor is priced at approximately 3.5 USD. Given this data, the estimated investment required to actualize the described power generation system stands at around 7840 USD. This amount underlines the economic practicality of the piezoelectric system, particularly when juxtaposed with the substantial electrical output it promises.

Taking into consideration various miscellaneous costs, we set the initial expenditure (I_t) at 8000 USD. Referring to Figure 10, we can ascertain that the average power generated per week is 4235.08 Watts, resulting in a total of 220 kW per year, which we denote as (E_t). This energy production figure is crucial for computing the Levelized Cost of Energy (LCOE).

Utilizing the LCOE formula and substituting the values, we find that the LCOE stands at approximately 15 cents/kWh (e.g., 0.15 USD/kWh), a result in close alignment with the findings outlined in [15]. A detailed comparison is summarized in Table II.

TABLE II
A COMPARISON OF THE LCOEs OF DIFFERENT TYPES OF ENERGY SOURCES

Type of Energy	LCOE (USD/kWh)
Piezoelectricity	**0.15**
Grid [24]	0.07 - 0.14
Biomass [22]	4.2 - 5.10
Photovoltaic [23]	0.10 - 0.15
Wind Turbines [23]	0.13 - 0.19
Thermoelectric [15]	0.95

This derived value can be effectively juxtaposed with other energy sources. Notably, it falls below the LCOE of thermoelectric generation systems, solar pavements [24], marginally

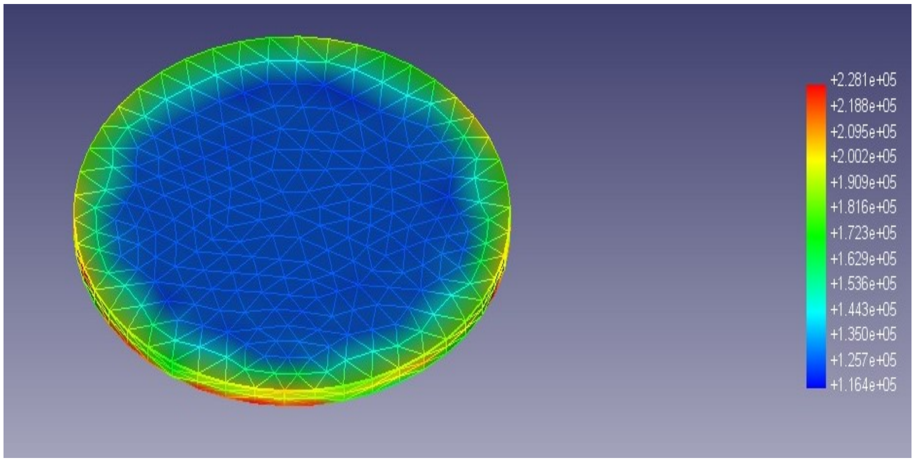

Fig. 7. Finite Element Method showing the von Mises Stress Distribution of a Piezoelectric Force Sensor Under a 600N Compressive Load.

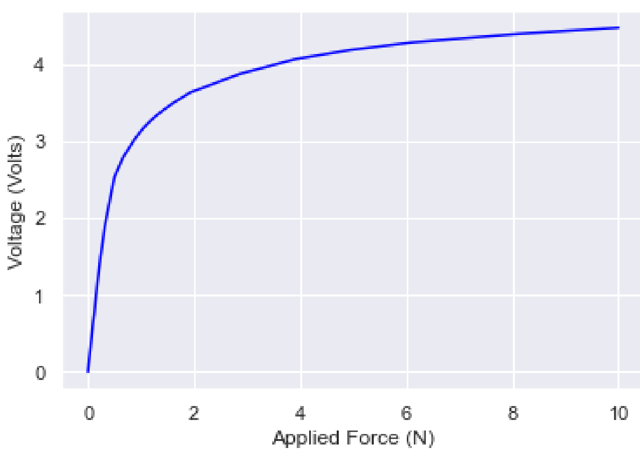

Fig. 8. The resulting force-voltage characteristic of the simulation.

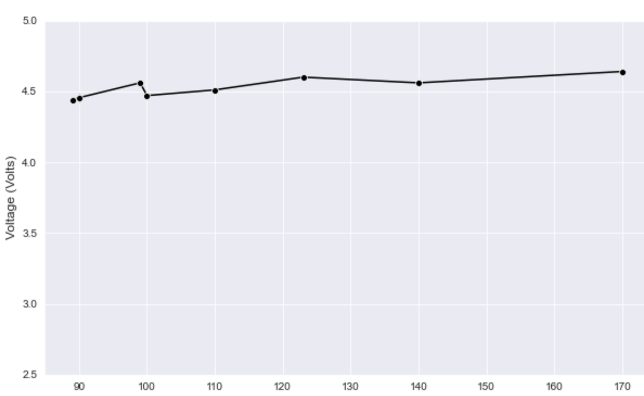

Fig. 9. Voltage Fluctuation with Respect to Load Resistance.

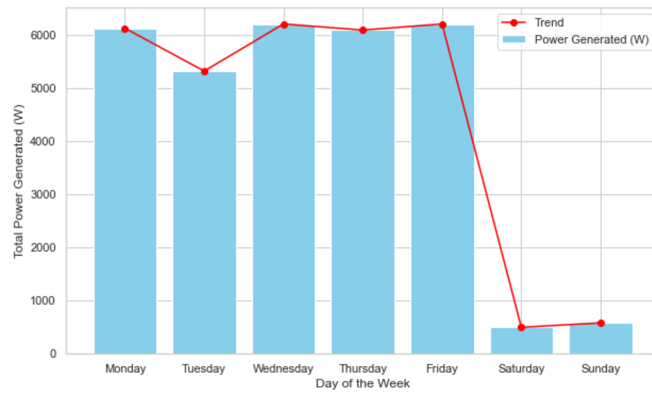

Fig. 10. Weekly Piezoelectric Energy Harvesting Trends in a University Campus.

below the cost of power generated from the grid [15] [23], and significantly below the power generated from the biomass [22].

The cost-to-benefit analysis revealed here highlights not just the system's affordability but also its potential for a rapid return on investment [17], thereby reinforcing the viability of piezoelectric solutions in sustainable energy initiatives.

V. Conclusion and Future Work

Throughout this paper, we have substantiated the promise of piezoelectric technology as a feasible, sustainable solution for energy harvesting in high-traffic academic settings for a smart campus. We have demonstrated through both simulation and practical implementation how the strategic placement and configuration of piezoelectric sensors can harness the kinetic energy of pedestrian traffic to effectively power campus infrastructure. Our findings reveal that parallel configurations of piezoelectric materials enhance the system's efficiency, culminating in a significant energy output of approximately 4.43 Watts per individual, which is showcased in the daily power generation trends. The scalability of the system is evident from the potential energy output relative to the number of pedestrians, suggesting a robust contribution to the university's green initiatives.

As we look to the future, further work needs to be done regarding possible piezoelectric material alternatives that can be used to generate electric power. By exploiting IoT (Internet of Things) technology, data collected from the piezoelectric system regarding energy production levels and pedestrian traffic patterns can be analyzed to optimize energy distribution and identify areas for infrastructure improvement. Finally, we suggest more investigation to be done to provide a more detailed cost analysis of the system especially when it comes to the revenue of the total system.

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