[11]. Piezoelectric sensors utilise the piezoelectric effect to measure changes in pressure, acceleration, temperature, strain, or force and convert this apparently wasted energy into an electrical charge.

In essence, this paper explores the paradigm shift towards renewable energy integration in sports facilities, underscoring the pivotal role of piezoelectric power generation in this transition. The rest of the paper is organised into the following sections; literature review, methodology and system design, results and discussions, future work and conclusion.

II. LITERATURE REVIEW

The demand for energy has been historically met by non-renewable sources such as coal, petroleum, and natural gas, which have played a foundational role in economic development. However, concerns regarding their rapid depletion and environmental consequences, including pollution and greenhouse gas emissions, necessitate a transition towards sustainable alternatives.

A. Energy Harvesting

The transition to renewable energy sources is crucial due to the depletion of traditional resources and their environmental impact [12]. This shift is evident in the increasing use of renewable energies, particularly in developed countries [13]. The potential of renewable sources, such as solar and wind power, is significant, and their costs are declining, making them increasingly viable [14]. However, challenges such as high upfront costs, lack of providers, and insufficient funding mechanisms need to be addressed [15]. At the centre of the use of renewable resources is a concept known as energy harvesting.

According to Eichhorn et al. [16], eenergy harvesting, or energy scavenging, involves extracting a small amount of energy from the surrounding environment through various sources. Sensors are widely used today due to their small size and low power consumption of electronic circuitry [17], and piezoelectric materials are a promising option for wireless sensor networks as they can convert mechanical energy into electrical energy with a simple structure [18]. Piezoelectricity is a critical technique for vibration-based energy harvesting, achieved by incorporating a beam or a plate with piezoelectric materials [19].

A basic energy harvester typically begins with a transducer, which converts mechanical energy into useful electrical energy. The axial symmetric structure of a piezoelectric plate makes it an attractive choice for easy processing into a MEMS system [20].

B. Historical Perspective on Renewable Energy in Sports Facilities

The integration of renewable energy technologies in sports facilities has evolved over time, with early examples including the use of solar panels for lighting and heating [21]. However, it was not until recent years that a more concerted effort has been made to harness renewable energy sources in sports venues. This evolution has seen the installation of wind turbines, solar arrays, and geothermal systems in stadiums and arenas, demonstrating the feasibility and benefits of renewable energy integration [21]. The potential for renewable energy systems in sports facilities is further underscored by the benefits of decentralised energy production, environmental impact reduction, and energy security [22]. However, Pavlas et al. [23] notes that the integration of renewable energy sources into existing energy production plants, such as combined heat and power systems, presents a significant challenge due to the variability and intermittency of these sources.

C. Current State of Renewable Energy Integration in Sports Facilities

Presently, there is a growing trend towards incorporating renewable energy systems in sports facilities worldwide, and Wanless et al. [24] posit that solar energy is the most widely adopted technology. This trend is driven by the need for cost-effective and sustainable energy solutions [25]. Wind turbines are also being installed in open spaces surrounding sports complexes to harness wind energy. Additionally, some stadiums are exploring the use of bioenergy from organic waste for heating and cooling purposes. These initiatives highlight the increasing recognition of the environmental and economic benefits of renewable energy integration in sports facilities.

D. Emerging Technologies and Innovations in Renewable Energy for Sports Facilities

A range of innovative technologies and strategies are being explored to enhance the sustainability of sports facilities. Innovations in energy storage, smart grid integration, and building-integrated renewable energy systems are key areas of focus. According to Habash et al. [26] smart micro grids optimise energy efficiency and reduce dependency on the grid. Advancements in battery technology enable better management of intermittent renewable sources. Hybrid energy systems, such as the one developed by [27] using a micro turbine and parabolic trough collector, are being explored to address the intermittent nature of renewable energy. Orynycz [28] highlights the potential of smart energy systems to decrease energy consumption in recreational facilities.

E. Future Prospects and Opportunities for Renewable Energy Integration in Sports Facilities

Looking ahead, the future of renewable energy integration in sports facilities appears promising yet complex. Emerging trends such as the electrification of transportation, decentralisation of energy systems, and increasing emphasis on sustainability drive the demand for renewable energy solutions. However, challenges remain, including policy uncertainty, funding constraints, and technological limitations. To capitalise on the opportunities presented by renewable energy, stakeholders must collaborate to address these challenges and leverage emerging technologies effectively. Human power generation, particularly from fitness equipment, has been explored as a viable energy source [29]. However, the unique energy needs of sports facilities, such as high heat and electricity loads, require careful consideration in the adoption of renewable energy sources [30].

F. *Using Piezoelectric Transducers to generate electricity in stadiums*

Research has shown that piezoelectric transducers can effectively generate electricity from mechanical energy, such as human footsteps [4,10,31-33]. This technology is based on the positive piezoelectric effect of the material. When the material is subjected to external pressure or stress, it deforms and creates a polarisation phenomenon, resulting in the accumulation of charges of opposite polarity on two opposite surfaces. When the external force is removed, the charges disappear accordingly. If the piezoelectric material is subjected to intermittent external force continuously, the charges appearing on the surfaces are collected by a charge collector and stored in energy storage equipment.

Overall, piezoelectric power generation has been proposed for use in public spaces, including stadiums, where the continuous pressure from large crowds can provide a sustainable energy source [33]. The cost efficiency and lower depreciation time of piezoelectric crystals make them a promising option for renewable energy production [34]. Furthermore, Minazara et al. [35] demonstrated the effectiveness of a piezoelectric diaphragm for vibration energy harvesting and its potential to power low consumption sensors.

G. *Harnessing sound energy from fans to generate electricity in stadiums*

Research has explored the potential of harnessing sound from fans in stadiums to generate electricity. Ge [36] and Sureshkumar [37] both discuss the conversion of sound to electricity, with Sureshkumar specifically focusing on industrial noise. Refaat et al. [38] proposes a smart energy management system for sports stadiums, which could potentially incorporate sound-generated electricity. A method for converting random sound energy into usable electric power that may be used in a stadium setting is presented by Jamal [39]. These studies collectively suggest that sound from fans in stadiums could be a viable source of electricity, with the right technology and management systems in place.

In conclusion, the integration of renewable energy systems in sports facilities represents a significant opportunity to advance sustainability goals and reduce reliance on non-renewable energy sources. While considerable progress has been made, significant challenges persist, requiring collaborative efforts from stakeholders across sectors. By embracing emerging technologies, policy frameworks, and funding mechanisms, sports facilities can position themselves as leaders in the transition towards a more sustainable energy future.

III. METHODOLOGY

This chapter presents the methodology employed in designing and implementing a Hybrid Piezo Power Generating System tailored for basketball courts, aimed at harnessing otherwise wasted energy. The success of this system hinges upon effective communication among integrated hardware components, facilitated by the Arduino Uno microcontroller.

The Hybrid Piezo Power Generating System is meticulously designed to convert mechanical energy into electrical energy, primarily through the utilisation of piezoelectric sensors. Secondly to convert sound as well into electrical energy. These sensors, embedded in basketball courts, capture mechanical stress generated by player movements and ball impacts. The resultant electrical energy is processed through a power conditioning circuit and stored in batteries, with system operation controlled by the Arduino Uno microcontroller.

A. *System Overview*

The system architecture is depicted in Figure 1, illustrating the interconnection and interaction among various system components, including piezoelectric sensors, power conditioning circuits, battery management systems (charging and discharging circuits), and the Arduino Uno microcontroller. The Arduino Uno board is used to monitor the charging rate of the battery and carry out the functions of the shot and game clock and the score board.

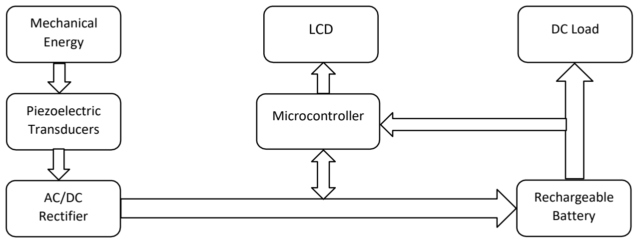


Fig. 1. System block diagram

B. *Hardware Design*

The hardware design comprises two primary units: the pressure-electrical energy conversion system and the audio-electrical energy conversion system.

1) *Pressure-Electrical Energy Conversion*

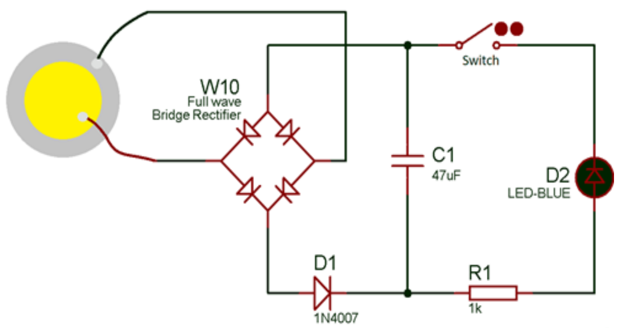


Fig. 2. Piezo-Rectifier connection [17]

This power generator operates on the principle of the piezoelectric effect. The piezoelectric effect refers to the ability of certain materials to generate electric charges when subjected to mechanical stress or pressure. When a piezoelectric crystal is squeezed or stretched, its structure deforms, causing net electrical charges to appear. These charges accumulate on the opposite outer faces of the crystal, resulting in net positive and negative charges on opposite crystal faces. This voltage is produced across the opposite faces of the crystal and is known as piezoelectricity.

In this system, a crystal disc senses the vibrations and produces a voltage across it. This voltage is measured and displayed on its display. Simultaneously, the voltage is utilised to charge the DC Battery.

2) Audio-Electrical Energy Conversion System

This section will discuss the process of converting sound energy into electrical energy using mechanical attraction. To start, sound can be analysed not only in the time domain but also in the frequency domain. When recording sound, it is typically represented in the time domain, where it can be plotted on a graph of time versus amplitude. In order to analyse sound in the frequency domain, a Fast Fourier Transform (FFT) can be performed. This was be done using MATLAB.

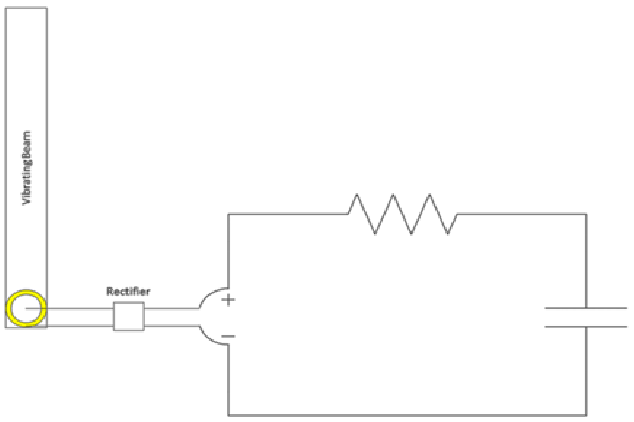


Fig. 3. Audio-Electrical system circuit [11]

The Euler–Bernoulli beam theory is used to design a cantilever beam to oscillate at such a frequency as to adsorb sound waves and convert their mechanical motion into electricity based on [40].

3) Other Components

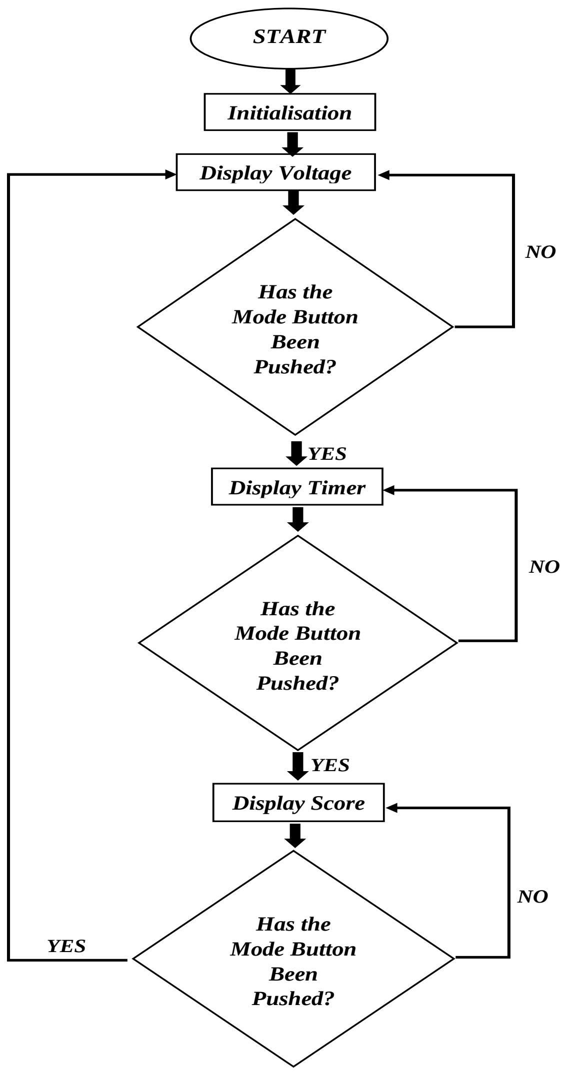
The output from the piezo power generator is fed into a bridge rectifier, which converts the alternating current (AC) into pulsating direct current (DC). The rectified AC to DC power goes through the smoothing capacitor before it is used to charge up the rechargeable lithium-ion battery by using lithium ions to store and release electrical energy. Lithium-ion batteries are preferred over other rechargeable batteries due to their high energy density, low self-discharge rate, and long lifespan.

A resistive voltage sensor is a type of sensor that works based on the principle of voltage division using resistors. The input voltage from the battery is applied across the series-connected resistors, and the output voltage is taken from the point between the two resistors. They provide a simple and cost-effective means of measuring voltage levels, and their accuracy can be improved by using precision resistors and careful calibration. An I2C 16x2 LCD display module consists of an I2C interface chip that provides a simple and effective means of displaying information in a wide range of applications, and its I2C interface reduces the number of pins required to control the display.

C. Software Design

The software design utilises Arduino IDE software, Fritzing, Proteus VSM, MATLAB, and PLX-DAQ to enable code development, circuit simulation, and data analysis to ensure efficient system operation and performance optimisation.

Fig. 4. Microcontroller based system flow chat



1) Software Tools

The Arduino IDE programmed and uploaded code to the microcontroller. Electronic circuits were designed and prototyped on the Fritzing system. Proteus Virtual System Modelling (VSM) simulated and tested electronic circuits and microcontroller-based embedded systems as shown in Figure 5. One of the key features of Proteus VSM is its ability to simulate the behaviour of microcontroller-based systems.

PLX-DAQ is a Parallax microcontroller data acquisition add-on tool for Microsoft Excel that can acquire up to 26 channels of data from any Parallax microcontrollers and drop the numbers into columns as they arrive. It provides easy spreadsheet analysis of data collected in the field, laboratory analysis of sensors, and real-time equipment monitoring.

MATLAB is a high-level programming language and interactive environment that is widely used for numerical computation, data analysis, and algorithm development. It provides a variety of built-in functions and tools for data analysis, signal processing, image processing, and more. MATLAB also has powerful graphics capabilities, which allow users to create high-quality visualisations of their data. It supports 2D and 3D plotting, as well as animation and interactive graphics

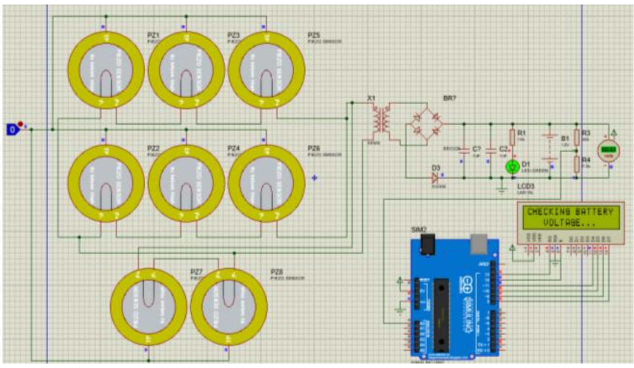


Fig. 5. Proteus circuit

In this case, courtside sounds were recorded using an audio recorder and the resulting sound waveform was transformed into the frequency domain using FFT. The frequency domain image showed that the highest amplitudes were present in the frequency ranges of 0 to 75 Hz and 100 to 250 Hz. A beam may be designed with a natural frequency that corresponds to the peak power frequencies of courtside noise using this information. Figure 6 shows the frequencies representing only the first mode resonance peaks.

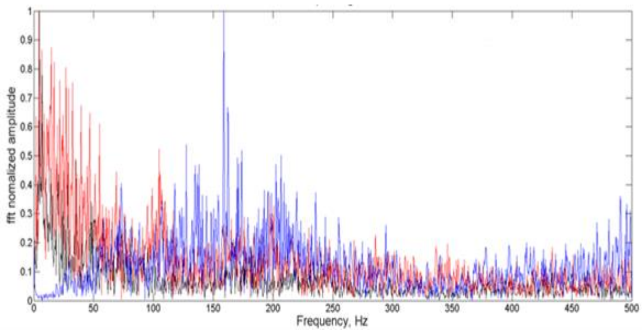


Fig.6. First mode resonance peaks

D. Implementation

The implementation phase involves integrating the designed hardware components, configuring software algorithms, and conducting real-time monitoring and verification of system performance. A summary of the steps:

- To design and implement a sound energy harvesting system.
- To design and implement kinetic energy harvesting system.
- To develop an AC to DC converter.
- To design a basketball game management and score keeper.

In summary, the methodology outlined herein provides a systematic approach to the design, implementation, and validation of the Hybrid Piezo Power Generating System for basketball courts.

IV. RESULTS AND DISCUSSION

A. Results

1) Subsystem 1: Pressure-Electric Conversion

For this subsystem, piezoelectric sensors were positioned beneath a plate to capture mechanical stress generated by player movements. Various configurations were tested to determine the optimal setup for power generation.

a) Comparative Study

TABLE I. COMPARATIVE STUDY OF DIFFERENT SETUPS

Setup	Maximum Current
1 Piezo Unit	Up to 40 uA
8 Piezo Connected in Parallel And 1 M Ohms	Up to 8.5 uA
8 Piezo Connected in Parallel And 1K Ohms	Up to 100 uA
8 Piezo Connected in Parallel And 680 Ohms	Up to 115 uA

Table I presents a comparative study of different setups, indicating the maximum current generated under various conditions. These results guided further experimentation to enhance power output.

b) Results of the Rectifier Circuit

TABLE II. POWER GENERATED FROM A RECTIFIER CIRCUIT

Time	Force	Load	Voltage	Current	Power
30s	735.75N	1MΩ	10V	8.5uA	8.5x10-5W
30s	735.75N	1kΩ	0.09V	100uA	9x10-6W
30s	735.75N	680Ω	0.06V	115uA	6.9x10-6W
30s	735.75N	100Ω	0.02V	140uA	2.8x10-6W

Table II illustrates the outcomes of the rectifier circuit tests, showcasing the voltage, current, and power generated under different load conditions. These findings informed subsequent steps to amplify power output.

Based on the results, solutions were sought to increase the power generated by the piezoelectric transducers. A circuit using the LM741 op-amp for the voltage and a Darlington pair using 2n3055 power transistor that amplifies both the current and the voltage generated was tested.

c) Results from the Amplifying Circuit

Table III displays the results obtained after implementing an amplifying circuit, highlighting increased power generation achieved through voltage and current amplification. However, challenges persisted in achieving desired power levels.

TABLE III. POWER GENERATED FROM AN AMPLIFYING CIRCUIT

Force	Load	Voltage	Current	Power
735.75N	2.5Ω	5V	2mA	0.01W
735.75N	1kΩ	5V	5mA	0.025W
735.75N	100Ω	5V	17mA	0.085W
735.75N	10Ω	5V	18mA	0.09W

d) Discussion

Despite efforts to amplify power output, challenges such as low voltage generation persisted, limiting the effectiveness of the amplifying circuit. Alternative strategies, including capacitor integration, were explored but proved inadequate due to insufficient power generation. Ultimately, the rectifier circuit remained the primary method for power generation in this subsystem.

2) Subsystem 2: Audio-Electric Converter

Oscillators equipped with piezoelectric sensors were employed to capture sound-induced vibrations. Experimental setups were conducted in university labs, utilising frequency analysis to identify resonance frequencies for optimal power generation.

In this case, court side sounds were recorded using an audio recorder, and the resulting sound waveform was transformed into the frequency domain using FFT. The resulting image showed that the highest amplitudes were present in the frequency ranges of 0 to 75 Hz and 100 to 250 Hz. Based on this information, a beam could be designed with a natural frequency that corresponds to the peak power frequencies of courtside noise as illustrated in Figure 6 showing the first mode resonance peaks.

a) Experimental Procedure and Results

To conduct experiments, three oscillators were created using different materials and the generated voltages when exposed to sounds of different frequency ranges were recorded. The resonance frequencies and the normalized voltage amplitudes between the oscillators were identified. An oscilloscope recorded the data because the Arduino UNO’s voltage was too low to be detectable at low sampling rates.

i. Aluminium 6061-T6 with a dual 8-inch design that operates at 20.55 Hz
ii. Nylon 6/6 and has a dual 8-inch design that operates at 8.12 Hz
iii. Nylon 6/6 and has a 2-inch by 3-inch design that operates at 129.99 Hz and 57.77 Hz, respectively.

Each oscillator was exposed to a sub-woofer as it played a frequency sweep from 1 to 200 Hz over a duration of 20 seconds. voltage from the piezoelectric wafers was measured at a sampling rate of 40 kHz from the wafers themselves and not the capacitors, this was to see the voltage being actively produced not the stored voltage.

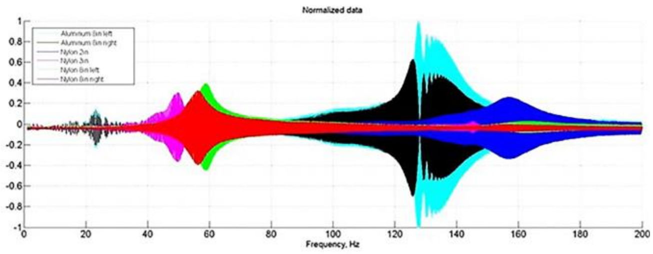


Fig. 7. Normalised data

Normalized data from laboratory testing identified resonance frequencies for different oscillator materials. Voltage-time plots revealed variations in voltage generation based on oscillator design and sound frequency.

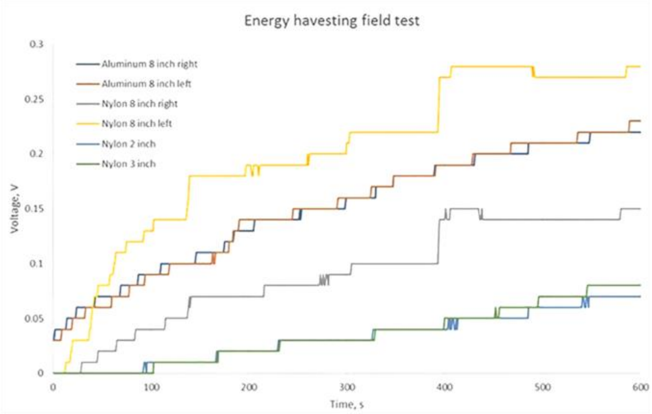


Fig. 8. Energy harvesting field test - Voltage-Time plot

To calculate the optimum lengths of the oscillators, the baseline court-side noise was used to perform a Fast Fourier Transform (FFT) to obtain the frequency domain of the signal, from which the frequencies with the highest amplitudes were identified. An oscillator would need to have a corresponding resonance frequency to take advantage of the energy within those high frequencies.

b) Field Test Results

Field tests corroborated laboratory findings, demonstrating the effectiveness of nylon oscillators in generating power from sound-induced vibrations. Analysis of natural frequency-beam length relationships informed oscillator design parameters for enhanced power generation.

When various materials are plotted, increase in length results in lower resonance frequency. Since piezoelectric wafers generate power from mechanical strain, I used nylon oscillators to produce more power since they have a lower Young's Modulus than steel or aluminium. A 4.7µF capacitor was used to reduce the charging time, as they reach near full capacitance within a second.

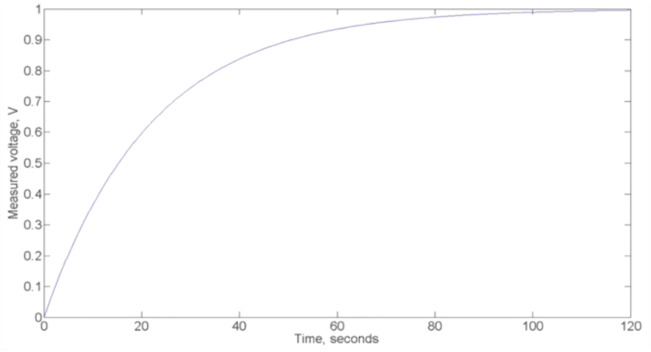


Fig. 9. Nylon oscillator generated voltage

When various materials are plotted, increase in length results in lower resonance frequency. Since piezoelectric wafers generate power from mechanical strain, I used nylon oscillators to produce more power since they have a lower Young's Modulus than steel or aluminium. A 4.7μF capacitor was used to reduce the charging time, as they reach near full capacitance within a second.

Nylon Oscillator generated voltage

c) Discussion

The utilisation of sound-induced vibrations for power generation showed promising results, with nylon oscillators emerging as efficient energy converters. By aligning oscillator design with resonance frequencies of court-side noise, significant power generation potential was realised.

3) Subsystem 3: Microcontroller

The microcontroller was integrated into the system to monitor battery voltage, manage game elements, and provide real-time data display functionalities. The system displayed the timer of both the game and shot on clocks, manipulated LEDs based on the time left on the shot clock, sounded a buzzer when the time ran out, displayed and adjusted the scoreboard to show the current scores of both teams. Figures 10 (a) and (b) illustrate the implementation of the clock mode and score mode respectively.

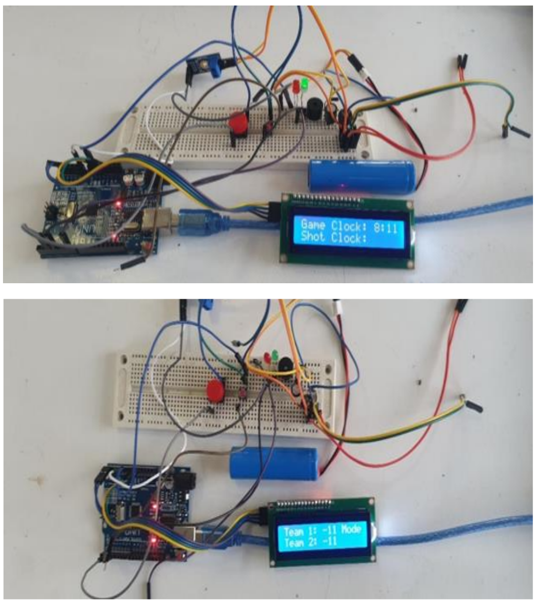


Fig. 10. Modes of operation: (a) Game clock mode, (b) Game score mode

Despite challenges, the system's ability to harness otherwise wasted energy sources signifies a significant step towards sustainability in sports facility operations. Further research and development are warranted to optimise system performance and foster widespread adoption of such renewable energy solutions in sports facilities.

V. FUTURE RESEARCH

Future research in the area of pressure-electric and audio-electric generators can focus on several key issues to address the limitations and enhance their practical applications namely; *Increasing Power Output*, *Optimising Conversion Efficiency*, *Scaling for Practical Applications*, *Environmental Impact Assessment*, *Integration with Energy Storage Systems, and Exploring Novel Applications.*

Overall, addressing these future research issues will contribute to the advancement of pressure-electric and audio-electric generators, paving the way for their widespread adoption as viable renewable energy sources in perpetually more noisy environments such as industry.

VI. CONCLUSION

Generating power from sound and pressure using piezoelectric sensors is a promising approach for harvesting energy from the environment. While challenges remain, further research and development in this field hold the promise of enhancing the performance and practicality of piezoelectric energy harvesting technologies. Current research related to piezoelectric power generation mainly concentrate in the fields of material science, mechanical science and microelectronic science, and certain limited and special application areas. Piezoelectric sensors can convert mechanical energy from sound waves and pressure changes into electrical energy with high efficiency, making them ideal for low-power applications such as phone charging and powering embedded devices.

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