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INTRODUCTION

The rapid evolution of digital technologies has fundamentally reshaped modern life, leading to an era where mobility, connectivity, and real-time information have become indispensable. From smartphones and smartwatches to health monitors and IoT-enabled wearables, personal electronics now form an integral part of daily routines, enabling seamless communication, enhanced productivity, and continuous access to data-driven services. However, the one persistent challenge that remains largely unresolved is the availability of reliable, portable, and sustainable power sources to keep these devices functioning uninterrupted. Traditional charging methods depend heavily on electrical grid access, thereby restricting true mobility and leaving users vulnerable to battery depletion, especially in remote or emergency scenarios.

In parallel, the global energy landscape is undergoing significant transformation. With fossil fuels depleting rapidly and environmental concerns reaching critical levels, the demand for clean, renewable, and decentralized energy alternatives is stronger than ever. This shift has prompted researchers to explore innovative solutions that harness renewable energy from the environment or human activity. One promising avenue within this domain is energy harvesting through biomechanical motion, particularly using piezoelectric transducers embedded in everyday wearables. The present project, “EcoPiezo PowerStore,” builds upon this vision by designing a smart, IoT-enabled, wearable energy harvesting system capable of converting human footsteps into electrical energy, thereby offering a sustainable, user-friendly, and weather-independent solution that bridges the micro-power gap faced by today’s mobile technology users.[1][5][8]

1.1 Preamble

1.1.1 The Global Energy Context

Energy is the foundational driving force of human civilization. Every technological process—from large-scale manufacturing to the functioning of microprocessors in personal devices—demands a continuous, reliable flow of energy. As society becomes increasingly digitized, our global dependence on energy has reached unprecedented levels. Even though advancements in electronics have improved energy efficiency, the absolute volume of devices in operation has dramatically increased. As a result, global energy consumption continues to rise sharply.

This escalation in energy demand has deep implications. Fossil fuels, which currently supply the majority of global energy, are finite resources. Their rapid depletion has accelerated greenhouse gas emissions, contributing directly to global warming, rising sea levels, and the degradation of ecosystems. International climate agreements emphasize the urgency of transitioning toward cleaner, renewable sources of energy to mitigate these environmental threats.

However, existing renewable energy infrastructures—solar farms, wind turbines, hydroelectric dams—are large-scale systems primarily designed for grid supply. Although indispensable, they possess inherent limitations:

Solar energy is weather-dependent and inactive during nighttime.

Wind energy requires specific wind speeds and suitable topography.

Hydroelectric projects rely on water resources, which are shrinking in many regions.

Moreover, these sources are stationary and cannot directly address the daily energy needs of individuals, particularly in portable or emergency scenarios. Humanity, therefore, faces a "micro-power gap"—a gap between the portable power we need and the power our mobility-centered lifestyle can support.

The solution lies in diversifying renewable energy systems and incorporating decentralized, individual-level energy harvesting methods. Such methods allow people to generate energy through everyday actions, thereby reducing the strain on centralized power grids.

1.1.2 The Rise of Wearable Technology and IoT

Simultaneously with the global energy crisis, the world is experiencing explosive growth in the Internet of Things (IoT) and wearable technologies. Smartwatches, fitness trackers, smart shoes, health monitors, AR/VR devices, and smartphones have become essential parts of modern life. These devices continuously monitor the user's health, location, physical activity, sleep quality, environment, and more.

However, despite their sophistication, these devices are fundamentally limited by their reliance on Lithium-Ion batteries. Once the battery is drained, the device's functionality collapses, making it unusable until recharged. This dependency forces users to stay connected to the electrical grid, limiting true mobility and freedom.

Heavy device usage—such as GPS navigation, Bluetooth connectivity, Wi-Fi communication, biometric tracking—intensifies battery consumption, causing frequent charging cycles and degrading battery lifespan.

This creates the need for:

- Portable, renewable, self-sustaining charging solutions
- Non-grid-dependent energy sources
- Wearable harvesting systems that generate power during daily activities

The future of IoT demands power systems that are as mobile as the devices themselves. This evolution aligns perfectly with the concept of energy harvesting—converting ambient energy (motion, heat, pressure) into electrical power.

1.1.3 Human Power: The Untapped Resource

Among all renewable resources, human kinetic energy remains one of the least explored yet most abundant. The human body is essentially a biomechanical engine capable of producing consistent mechanical force. The average person takes between 3,000 and 10,000 steps daily, generating significant kinetic energy during the walking gait cycle, especially during:

- Heel-strike (Impact phase)
- Mid-stance (Load-bearing phase)
- Toe-off (Propulsion phase)

Under normal circumstances, the energy generated in each step is absorbed by the shoe’s cushioning and dissipated as heat. This represents an enormous reservoir of wasted energy.

Piezoelectric transducers offer a unique opportunity to convert this mechanical stress into electrical energy. The EcoPiezo PowerStore project leverages this principle: embedding piezoelectric discs into footwear to harvest energy created by natural walking movements.

This transforms human locomotion into a renewable energy source—an elegant demonstration of sustainability through daily actions.

1.2 Problem Statement

1.2.1 The “Low Battery” Anxiety (Nomophobia)

Over the years, mobile phones have shifted from being simple communication tools to becoming an essential part of everyday life. People now depend on their devices for staying connected with family, navigating unfamiliar places, accessing healthcare information, completing work, attending online classes, making payments, and even ensuring personal safety. Because of this deep dependency, a low battery often creates a sense of nervousness or discomfort. This feeling is commonly referred to as **Nomophobia**, which describes the fear of losing access to one’s mobile phone. The moment the battery drops to a critical level, many users experience stress because they know their ability to communicate, access information, or call for help can suddenly disappear.

This worry becomes far more serious in situations where mobile devices are not just helpful but necessary:

a) Travelers and Trekkers

People who travel through remote areas—such as mountains, dense forests, or long-distance trails—rely heavily on their phones. They use them for navigation, checking routes, receiving weather alerts, and staying in touch with others. In such places, losing battery power is not just inconvenient; it can put a person at risk. Without their phone, they may not be able to call for help, find the correct path, or share their location with rescue teams, which can lead to dangerous situations.

b) Daily Commuters

For those who commute to work or college every day, mobile phones have become essential companions. Commuters depend on their devices for booking rides, tracking buses or trains, listening to music, making digital payments, or simply passing time during long journeys. With continuous use of the internet and apps, the battery often drains faster than expected. If there is no charging point available during the trip, it can leave the person disconnected right when they may need their phone the most.

c) Students and Working Professionals

Students frequently use their phones to attend classes, download notes, scan documents, take photographs of assignments, or join meetings. Working professionals depend on their devices for emails, project discussions, accessing office tools, or navigating to client locations. When they are outdoors for long hours, at seminars, internships, workshops, or field visits, charging opportunities are often limited. A low battery can disturb their workflow and cause unnecessary pressure, especially when important tasks or deadlines depend on mobile access.

1.2.2 Limitations of Existing Portable Solutions

Despite the wide range of portable charging devices available today, none of them offer a truly dependable and self-sustaining source of power for people who are constantly on the move. As modern lifestyles demand uninterrupted access to smartphones and wearable gadgets, the shortcomings of current charging options become increasingly clear. While these solutions may provide temporary relief, they fail to address the root problem—**the need for continuous, renewable, and hassle-free power generation without relying on electricity or weather conditions**.

a) Power Banks

Power banks have become the most commonly used backup for low-battery situations. However, they come with several practical limitations that reduce their usefulness in real-world situations.

- **Bulky and inconvenient**: High-capacity power banks are often heavy and thick, making them uncomfortable to carry in a pocket or small bag. This reduces the convenience that they are supposed to provide.
- **Require prior charging**: Power banks do not create energy; they only store it. If the user forgets to charge the power bank before leaving home, it becomes as useless as a dead phone.
- **Limited backup cycles**: Once the stored charge is used, the power bank cannot recharge itself. It still needs access to a wall socket, tying the user back to the grid.
- **No renewable capability**: Power banks do not reduce dependency on electricity. They simply delay the problem temporarily.

Because of these drawbacks, power banks are not a long-term or sustainable answer for people who spend long hours outdoors or in places without reliable electricity.

b) Solar Backpacks and Solar Chargers

Solar charging is often marketed as an eco-friendly and futuristic solution. However, the practical performance of portable solar devices is far from reliable.

- **Dependent on sunlight**: Solar panels need direct exposure to strong sunlight to work efficiently. Indoors, at night, during the rainy season, or even on a mildly cloudy day, their effectiveness drops drastically.
- **Slow charging speeds**: Even under ideal sunlight, solar chargers take a long time to generate enough energy for modern phones, which require significant power.
- **Fragile and expensive**: The thin solar cells integrated into backpacks or small chargers are prone to scratches and breakage. Replacing or repairing them is costly.
- **Not suitable for fast-moving users**: Travellers, trekkers, cyclists, or commuters rarely stay in one place long enough for solar panels to charge effectively.

Thus, while solar energy is sustainable in theory, it is not dependable as a primary portable energy solution for individuals with unpredictable schedules.

c) Stationary Piezoelectric Floors

Innovative public infrastructure projects have experimented with piezoelectric flooring systems that generate electricity through human footsteps. Although these installations showcase the potential of kinetic energy harvesting, they have several limitations:

- **They are not portable**: These systems are installed permanently in public spaces such as airports, railway stations, malls, and stadiums. Individuals cannot carry or use them when they need power in remote or outdoor environments.
- **Require large crowds**: These floors generate meaningful amounts of energy only when thousands of people walk across them daily. A single user cannot benefit personally.
- **High installation costs**: Constructing piezoelectric floors requires specialized materials, large surface areas, and infrastructure upgrades, making them too expensive for individual use.
- **No direct benefit to user devices**: The energy generated typically goes into public utilities rather than personal charging needs.

1.2.3 The Lack of "Smart" Feedback

Although several energy-harvesting prototypes have been developed in recent years, most of them overlook an important aspect of modern technology—the user's need for clear, interactive feedback. People today are accustomed to real-time information through mobile apps, fitness trackers, and smart devices. When an energy-harvesting system does not show the user what is happening, it becomes difficult for them to understand its usefulness or stay motivated to use it. Many existing designs simply generate energy in the background without offering any information about how much power is being produced or how the user's movement affects the system. As a result, the entire process remains invisible, causing the user to lose interest quickly.

This lack of interaction creates several gaps:

a) No Visibility of Power Generation

Users cannot see how much energy is being produced at any moment. Without this information, it is hard for them to appreciate the impact of their effort or understand the system's performance.

b) No Real-Time Feedback

Modern users expect instant updates. When energy data is not displayed in real time—such as live voltage spikes or step-based electricity generation—the system feels unresponsive and outdated.

c) No Motivation or Incentive to Walk More

Energy harvesting works best when the user stays active. However, without interactive feedback or progress indicators, users have no reason to increase their steps or walking pace to produce more energy.

d) No Historical Tracking or Analytics

Most prototypes lack features that store past data. Without daily or weekly analytics, users cannot compare their activity patterns, track improvements, or understand their long-term energy contribution.

To make energy harvesting truly user-friendly and practical, a modern wearable solution must be **smart** and **interactive**. This requires:

- **IoT connectivity** to send data to cloud storage
- **Mobile app dashboards** for easy monitoring
- **Real-time voltage or power graphs**
- **Step counters and activity tracking**
- **Calorie estimation for fitness motivation**
- **Battery status indicators** showing stored energy levels

When such features are absent, even well-designed prototypes feel incomplete because the user is unable to connect with the technology in a meaningful way. This lack of engagement is one of the key reasons why existing systems remain mostly experimental rather than practical for everyday use.

1.3 Motivation

1.3.1 The Convergence of Green Tech and IoT

The development of the **EcoPiezo PowerStore** is inspired by the merging of two major technological movements: the global shift toward **sustainable engineering** and the rapid growth of **Internet of Things (IoT) technologies**. As society becomes more environmentally conscious, there is an increasing effort to design systems that reduce dependency on non-renewable energy sources and encourage greener alternatives. At the same time, modern users have grown accustomed to smart devices that can collect data, interpret patterns, and provide meaningful insights. Bringing these two worlds together opens up a powerful opportunity for innovation. One of the guiding ideas behind this project is the concept of **Parasitic Energy Scavenging**, which involves capturing small amounts of energy generated naturally by the user without causing any discomfort or change in their normal activity. Walking, running, and everyday movements produce a surprising amount of unused mechanical energy. By integrating **piezoelectric transducers** into footwear, this project aims to reclaim that wasted energy and convert it into a usable electrical form.

What sets the EcoPiezo PowerStore apart from earlier piezoelectric attempts is the addition of a smart technology layer. Using the **ESP32 microcontroller**, which offers built-in Wi-Fi and Bluetooth capabilities, the system can collect real-time energy data and transmit it wirelessly to the **Google Firebase** cloud platform. This combination transforms a simple mechanical-to-electrical conversion system into a **connected, intelligent, and data-driven energy harvesting solution**.

Instead of functioning merely as a passive charger, the EcoPiezo PowerStore becomes an active participant in the user's lifestyle—measuring steps, tracking generated power, analyzing activity patterns, and displaying energy statistics through a mobile app. This fusion of green technology with IoT not only promotes sustainability but also engages users by showing them the direct impact of their movements, making renewable energy generation a part of their daily routine.

1.3.2 Gamification of Fitness and Sustainability

One of the strongest motivations behind the EcoPiezo PowerStore is the growing cultural trend of **self-tracking and performance monitoring**. Today's users are highly engaged with apps and wearables that record steps, heart rate, calories burned, sleep patterns, and overall fitness progress. People enjoy seeing measurable results, setting daily goals, and comparing their achievements over time. This project builds on that mindset by turning the process of energy harvesting into an interactive and rewarding experience.

With the smart features integrated into the system, walking is no longer just a routine physical movement—it becomes a **dual-purpose activity** that benefits both the user and the environment:

a) Health Benefit

More steps contribute to improved fitness, better cardiovascular health, and increased daily activity levels.

b) Energy Benefit

Every additional step also generates a small amount of electrical energy, making the user an active participant in renewable power production.

To support this idea, the accompanying mobile application provides an engaging dashboard that displays various real-time and analytical metrics, such as:

- **Live voltage spikes** generated with each step
- **Total step count** recorded throughout the day
- **Energy produced** in milliwatt-hours (mWh)
- **Calories burned**, calculated from movement patterns
- **Daily, weekly, and monthly charts**, helping users track their progress over time

By presenting this data visually, the system turns ordinary walking into a motivating activity. Users can challenge themselves to walk more, improve their energy contribution, or even compete with friends. This combination of fitness tracking and sustainable energy awareness makes the EcoPiezo PowerStore not just a technical innovation, but also a tool that encourages healthier habits and environmental responsibility.

1.3.3 Emergency Reliability

One of the most compelling motivations for developing the EcoPiezo PowerStore is its potential usefulness during emergencies. Natural disasters such as earthquakes, floods, cyclones, and landslides often lead to widespread power outages that can last for hours or even days. In such situations, access to a stable electricity source becomes one of the biggest challenges. People may find themselves with low battery levels at a time when communication is absolutely critical—whether it is to call for help, receive alerts, or stay connected with rescue teams.

A wearable energy harvester offers a unique advantage in these high-risk conditions. Since it generates power directly from human movement, users can produce essential electricity simply by walking, even when all external power sources are unavailable. This capability can make a significant difference in life-threatening scenarios. For instance, the energy generated could be enough to:

- **Place an emergency call** to authorities or family members,

- **Send GPS coordinates** to help rescuers locate the individual,
- **Power essential sensors or communication applications** on a smartphone,
- **Keep a device functioning long enough for assistance to arrive**.

Unlike power banks, which can run out of charge, or solar chargers, which depend on sunlight, a wearable piezoelectric system remains functional as long as the user is able to move. This independence from environmental conditions and electrical infrastructure makes it an extremely reliable backup solution during crisis situations.Therefore, beyond its everyday convenience, the EcoPiezo PowerStore holds the potential to become a life-saving technology—providing a self-sustaining source of energy when it is needed the most.

1.4 Objectives

The EcoPiezo PowerStore project is guided by four clear and measurable objectives that shape the design, development, and evaluation of the final prototype. Each objective reflects a critical aspect of the system—from harvesting energy efficiently to presenting the data in a user-friendly, smart interface. Together, these goals ensure that the project is not only functionally sound but also practical, interactive, and aligned with modern IoT trends.

Objective 1: Design of a High-Efficiency Wearable Harvester

Sub-goal:
To understand the biomechanics of human walking and identify the regions of the foot that experience the highest pressure during each step.

Implementation:

- Piezoelectric Transducers (PZT discs) are embedded strategically in the **heel** and **toe** regions, where impact force is greatest.
- Multiple PZT discs are connected in a **parallel configuration** to boost current output, since piezoelectric elements naturally generate high voltage but low current.

Target:
To effectively convert the pressure exerted by an average individual weighing 60–80 kg into usable AC voltage that can be processed and stored for later use.

Objective 2: Implementation of Efficient Power Management & Storage

Sub-goal:
To convert the raw, uneven AC output of piezoelectric discs into a stable and safe DC supply suitable for charging and storage.

Implementation:

- A **Full-Wave Bridge Rectifier** using Schottky diodes is employed to minimize forward voltage losses, improving overall efficiency.
- A **smoothing capacitor** is added to reduce voltage fluctuations and stabilize the DC output.
- A **voltage regulator or Zener diode** ensures that the output does not exceed safe limits (typically 5V).
- The harvested energy is stored safely in a **Li-ion rechargeable battery** or **supercapacitor bank**, supported by protection circuitry.

This power management system ensures predictable performance and protects all connected components from over-voltage or instability.

Objective 3: Enablement of IoT Connectivity

Sub-goal:
To transform the harvested energy data into a digital form that can be transmitted, monitored, and recorded in real time.

Implementation:

- An **ESP32 microcontroller** is used for data acquisition due to its low power consumption and built-in Wi-Fi/Bluetooth features.
- The ESP32 syncs information wirelessly to the **Firebase Realtime Database**, ensuring seamless cloud logging.
- Users can access key information such as:
    - **Live voltage levels**
    - **Daily or weekly energy generation statistics**
    - **Step count and activity analytics**

This IoT integration not only enhances user engagement but also adds transparency and intelligence to the overall system.

Objective 4: Development of a User Interface (Android App)

Sub-goal:
To present the energy harvesting data in a clear, appealing, and interactive manner through a mobile application.

Implementation:
Using **MIT App Inventor**, an easy-to-use Android app is developed featuring:

- **Real-time voltage graphs** that update as the user walks
- **Step count display** integrated with ESP32 readings

- **Battery charge status** showing the stored energy
- **Calorie estimation** calculated from movement data

This interface completes the wearable energy ecosystem by making invisible energy visible, motivating users to stay active, and strengthening their engagement with renewable energy technology.

1.5 Scope of the Project

The EcoPiezo PowerStore project has been developed with a clear and practical scope that defines its technical capabilities, possible applications, and existing limitations. This section presents what the system can realistically achieve in its prototype stage, how it can be applied in real-world situations, and what boundaries must be considered for future refinements.

1.5.1 Technical Scope

The technical scope of the EcoPiezo PowerStore centres on designing a functional wearable prototype that integrates piezoelectric transducers into footwear. The system is engineered to capture the mechanical pressure generated while walking and convert it into electrical energy. This harvested power is then processed, stored, and visualized through IoT-enabled components. One of the core capabilities of the system is its ability to charge low-power electronic devices. The generated energy is most suitable for operating small gadgets such as fitness trackers, Bluetooth accessories, wearable health sensors, LED indicators, and microcontroller-based modules. Although the output is not sufficient to fully charge smartphones, the device can still provide a small but valuable emergency boost—usually around 1–2%—which is enough to make an urgent call, send GPS coordinates, or perform essential communication during emergencies.

Another major technical capability is the system's IoT connectivity, made possible through the ESP32 microcontroller and Firebase cloud integration. This allows real-time synchronization of voltage readings, step counts, and other metrics, enabling users to monitor power generation as it happens. The Firebase database supports long-term data storage, allowing users to analyse trends, evaluate weekly or monthly performance, and study how their walking patterns influence energy output. Over time, the stored data forms a meaningful log that helps users understand their daily energy contribution.

The project also incorporates a strong data analytics component. Instead of simply generating energy, the system transforms raw sensor data into structured insights. Users can track their historical performance, compare walking patterns, and understand how variations in step frequency or pace affect energy production. Daily averages reveal typical energy output, providing a clear picture of how much power they generate on a regular basis. In addition, the system encourages engagement through gamification features such as step-based challenges and weekly competitions. This not only motivates users to walk more but also strengthens the connection between personal fitness and sustainable energy generation.

1.5.2 Application Scope

The EcoPiezo PowerStore system has a wide range of potential applications across multiple fields. While the current phase demonstrates a prototype model, future iterations could be adapted and scaled for various needs.

1. Military Use

For soldiers in remote terrains, carrying heavy battery packs is both tiring and impractical. A built-in energy harvester in their boots could:

- Provide backup power for communication devices
- Operate GPS modules or encrypted radios
- Reduce dependency on external charging equipment

This enhances endurance and efficiency in field operations.

2. Healthcare Use

In the medical domain, piezoelectric energy can assist in powering small implantable or wearable devices. Future advancements could contribute to:

- Low-power pacemakers
- Continuous health monitoring sensors
- Smart prosthetics
- Wearable ECG/EMG modules

This reduces frequent battery replacements and increases device reliability.

3. Adventure, Tracking & Safety

For trekkers, hikers, children, or individuals in remote areas, the device can support:

- GPS tracking
- Emergency SOS signalling
- Wildlife research trackers
- Search and rescue equipment

Since the system relies on movement, it remains operational even when isolated from the grid.

4. Smart Wearables

The energy output can sustain multiple micro-gadgets such as:

- Bluetooth beacons
- Step-count sensors
- Motion trackers
- Smart shoe modules

This forms the foundation for next-generation wearable ecosystems.

1.5.3 Limitations (Boundary of Scope)

While the EcoPiezo PowerStore presents valuable innovations, it also has limitations that must be recognized. One major limitation is the low current output of piezoelectric materials. Although they generate high voltage, the actual current is relatively small, which limits the amount of energy that can be harvested during normal walking. As a result, the system is suited primarily for low-power devices rather than high-drain electronics. Another limitation is that the technology depends directly on user activity. If the user walks less or remains stationary for longer periods, energy production decreases accordingly. This means that the system performs best for highly active users.

As a prototype, the device still requires improvements in areas such as long-term durability, waterproofing, and shock resistance. The embedded piezoelectric discs must withstand repeated compression, environmental exposure, and long-term wear, which may require advanced materials or additional protective layers in future iterations. Finally, the EcoPiezo PowerStore should be considered a supplementary source of renewable power rather than a full replacement for traditional chargers. It is designed to provide backup energy, emergency support, and small-scale power harvesting, not to replace high-capacity wall chargers or power banks.[2][4]

1.6 Summary

This chapter introduces EcoPiezo PowerStore, a wearable system that generates electrical energy from footsteps using piezoelectric discs embedded in footwear. It addresses the growing need for portable and renewable power as modern devices require constant charging. The chapter explains the limitations of current solutions like power banks and solar chargers while highlighting the potential of harvesting energy from daily human movement. The system uses IoT integration through ESP32 and Firebase to display real-time voltage, step count, and activity data on a mobile app. Key objectives include efficient energy conversion, smart power management, cloud connectivity, and a user-friendly interface. It also covers practical applications in military, healthcare, safety, and smart wearables, while noting limitations such as low current output and reliance on user activity. Overall, the chapter positions EcoPiezo PowerStore as a supportive, eco-friendly micro-energy solution for modern users.

LITERATURE SURVEY

CHAPTER II

LITERATURE SURVEY

Research on piezoelectric energy harvesting has grown rapidly in the last decade, driven by the increasing need for self-powered wearable systems, portable devices, and sustainable micro-energy solutions. Several studies have explored how mechanical energy produced through human locomotion—such as walking, running, or standing pressure—can be effectively converted into electrical energy using piezoelectric materials. Earlier works mainly focused on basic piezoelectric tiles and small-scale prototypes, where the generated power was limited due to material inefficiency, irregular pressure distribution, or poor mechanical design. However, modern approaches have significantly improved harvesting capability by optimizing electrode arrangements, selecting high-performance piezo materials, and integrating power-conditioning circuits to stabilize output voltage. Researchers such as WAK Shume et al. (2024) have reviewed advancements in piezoelectric materials including ceramics, polymers, composites, and thin films, highlighting that innovations in material science directly influence conversion efficiency, durability, and energy density. Many studies also emphasize the importance of designing the mechanical structure—such as multilayer plates, stepped beams, and optimized pressure points—to maximize deformation and therefore electrical charge generation.

Footstep-based electrical energy generation is one of the most active areas within piezoelectric research. Numerous authors have proposed systems where piezoelectric sensors are embedded inside shoes or flooring tiles to capture the pressure exerted during walking. Ali et al. (2019) successfully developed a shoe-based energy harvester using twelve piezo plates connected to a rectifier, boost converter, and voltage regulator, producing a stable 5V output suitable for charging smartphones during walking. Similarly, other researchers have demonstrated conceptual and real-time models where piezoelectric tiles installed in public places such as railway stations, malls, and pavements produce measurable voltage from human traffic. These systems typically involve processes like AC-to-DC conversion, voltage boosting, and energy storage using capacitors or rechargeable batteries. Studies also show that proper placement of the piezo elements—especially at high-pressure foot zones such as the heel and toe—significantly increases generated output. Smart-shoe research further extends the application by integrating sensors, emergency lights, obstacle-detection modules, and microcontrollers, proving that piezo-based harvesting can support multifunctional wearable systems.

While piezoelectric energy harvesting shows strong potential, several challenges remain across existing studies. Many prototypes still produce low current, limiting them to small devices unless paired with storage units. The lifespan of piezo crystals can also decrease under continuous stress, and performance drops when pressure is uneven. Even so, improvements in power electronics, advanced piezo materials, and flexible structures have led to more reliable designs. Recent research highlights the need for smarter power-management circuits, stronger mechanical support, and protective layers to improve durability. These gaps motivate the creation of the EcoPiezo PowerStore system, which aims to deliver a more stable, efficient, and user-friendly solution.

2.1 TITLE: Energy Harvesting from Human Locomotion Using Piezoelectric Transducer-Based Shoe

AUTHORS: M. T. Ali, T. J. Khalid, A. Ahmed, N. E. R. Sashiq-Un, M. R. N. Nancy

PUBLISHED YEAR: 2019

DESCRIPTION

This work presents a piezoelectric shoe designed to generate electricity from everyday walking. The researchers placed twelve piezoelectric plates inside the sole and connected them to a rectifier, boost converter, and voltage regulator. When a person walks, the mechanical pressure on the plates produces AC voltage, which is then converted into a stable 5V DC output suitable for charging small electronic devices. Both simulation and prototype testing showed that the system can deliver continuous power while walking, making it a practical approach to on-the-go energy harvesting [5].

ADVANTAGE

- Produces a regulated 5V output that can charge a smartphone.
- Uses natural human movement as a renewable power source.
- Demonstrated stable performance with up to 3W power generation during walking.

DISADVANTAGE

- The current output was lower than expected (600 mA instead of 1 A).
- Requires long walking or jogging durations to fully charge a phone.

2.2 TITLE: Energy Conservation Using Piezoelectric Effect Through Modern Technology

AUTHORS: P. Chinnasamy, K. Dhathri, P. Deepalakshmi, K. Sai Sri, K. Durga, K. N. L. Lavanya

PUBLISHED YEAR: 2024

DESCRIPTION

This paper highlights the use of piezoelectric materials in modern systems to reduce energy consumption and promote sustainable power generation. It explores how piezoelectric cells can be integrated into shoes, belts, flooring tiles, and compact electronic devices to convert everyday mechanical activities into usable electrical energy. The authors review different prototypes and evaluate them based on energy efficiency, durability, material strength, and environmental resistance.

Furthermore, the paper discusses advancements in piezoelectric materials such as PVDF films, ceramic composites, and multilayer structures, which have significantly improved power output and responsiveness. It also addresses practical challenges like irregular pressure distribution, material fatigue, circuit losses, and long-term stability [10].

ADVANTAGE

- Covers a wide range of practical applications, from wearables to infrastructure.
- Presents performance data comparing various piezoelectric products.

- Promotes scalable and environmentally friendly energy solutions.

DISADVANTAGE

- Many designs are still conceptual and need physical validation.
- Some piezoelectric materials still face challenges like efficiency loss and limited lifespan.

2.3 TITLE: Generation of Electricity Using Shoes (Smart Shoe System)

AUTHORS: S. K. Pawar, A. S. Nigade, S. Harjai, P. Goel, N. Narwal

PUBLISHED YEAR: 2020

DESCRIPTION

This study presents a smart shoe system designed to generate electricity using piezoelectric crystals placed at key pressure points of the foot. Each step produces mechanical stress on the piezo elements, generating electrical energy that is rectified and stored in a rechargeable battery. The concept demonstrates how everyday walking can be converted into a practical power source without relying on external electricity.

The stored energy can be used to support useful functions such as mobile charging, emergency lighting, and obstacle detection for visually impaired users. The paper explains the overall working mechanism, including the placement of piezo discs, the rectifier circuitry, and the storage module. The study highlights the possibility of integrating smart features into footwear while promoting renewable, user-generated energy [1].

ADVANTAGES

- Supports multiple smart-shoe applications like charging, navigation assistance, and lighting.
- Uses scientific placement of piezo discs for higher energy output.
- Clear circuit diagrams and practical implementation details.

DISADVANTAGE

- Power output depends heavily on the user’s walking pattern.
- Additional modules increase overall design complexity.

2.4 TITLE: Energy Generation from Footsteps Using Piezoelectric Sensors

AUTHORS: S. G. C., A. R. K. H., B. M. Biju, P. L.

PUBLISHED YEAR: 2021

DESCRIPTION

This paper focuses on a footstep power-generation tile that uses an array of piezoelectric discs to convert walking pressure into electrical energy. The system includes rectification, storage in a battery, and control using RFID authentication. Experimental results showed that increasing the number of piezo discs significantly increased voltage output, reaching up to 10.9V with six discs. The study includes block diagrams, conceptual designs, prototype images, and V-I characteristics to validate its performance. It also highlights how such tiles can be installed in high-footfall public areas to maximize power generation from human movement. The authors further emphasize that although the output is modest, the system is suitable for powering low-energy applications such as lighting, counters, and IoT sensors [2].

ADVANTAGE

- Voltage output increases effectively by increasing the number of piezo discs.
- Includes a functioning prototype with RFID-controlled power access.
- Suitable for public spaces like staircases, malls, and railway platforms.

DISADVANTAGE

- Current output is low (microamp range), limiting high-power applications.
- Efficiency depends on proper pressure distribution and mechanical design.

2.5 TITLE: Footstep Power Generation Using Piezoelectric Sensor

AUTHORS: N. J. Helonde, P. Suryawanshi, A. Bhagwatkar, A. Wagh, P. Vetal

PUBLISHED YEAR: 2021

DESCRIPTION

This paper presents a system that generates electricity from footsteps using piezoelectric sensors. When a person walks, the pressure applied on the piezo discs produces electrical energy, which is then regulated and stored through a rectifier, voltage regulator, microcontroller, and battery. The system includes components such as an LCD display, LDR, voltage booster, and a mobile-charging interface.

The flow of the system—from sensing pressure to boosting voltage—is illustrated through the block diagram and simulation circuit (visible on pages 3–4 of the document). Practical testing showed that the voltage output from footsteps can be increased to usable levels for small electronic loads. The paper highlights the potential of using human movement in crowded areas such as malls, pavements, bus stands, and railway stations for sustainable micro-energy generation [4].

ADVANTAGE

- Electricity is produced simply by walking, without requiring any fuel.
- Works effectively in crowded public places where foot traffic is high.
- Produces clean, renewable energy from daily human movement.
- Once installed, the system is low-maintenance and self-generating.

DISADVANTAGE

- Output energy is limited and suitable only for small loads.
- Efficiency depends heavily on the amount of pressure applied.
- Piezoelectric crystals can wear out over time under continuous stress.
- Not suitable for large-scale power requirements.

2.6 TITLE: Footstep Power Generation Using Piezo Electric Sensor

AUTHORS: Isha Tripathi, Alfisha Naaji, Anjali Gautam, Naini Sonkar, Dr. Saiyed Salim Sayeed

PUBLISHED YEAR: 2023

DESCRIPTION:

This research focuses on harvesting electrical energy from daily human movement, specifically footsteps. The study discusses a practical system where piezoelectric tiles convert the pressure applied by walking into usable electrical power. The electrical energy produced is channelled through rectification, regulated, and stored in a rechargeable battery for later use. Supporting components such as a microcontroller, inverter, and display unit help monitor and manage the system efficiently.

The findings highlight that although a single piezoelectric disc generates only a small amount of voltage, using multiple discs together significantly increases the output. During experimental testing, the power collected from footsteps was successfully used to operate basic electrical loads, demonstrating real-world usefulness for small-scale energy needs. The system is particularly suitable for public locations with high pedestrian movement such as bus stands, schools, shopping centres, and railway stations, where the generated energy can be collected continuously throughout the day [9].

ADVANTAGES

- Produces electricity naturally from walking without any fuel source.
- Performs well in locations with high public foot traffic.
- Environment-friendly method of renewable micro-energy generation.
- Operates with low maintenance once properly installed.

DISADVANTAGES

- Generates a limited amount of power, suitable only for small loads.
- Energy output depends on the pressure applied by footsteps.
- Piezoelectric materials may deteriorate due to long-term mechanical stress.

2.7 TITLE: Foot Step Power Generation Using Piezoelectric Materials

AUTHORS: Baswaraj Gadgay, Shubhangi D.C, Abhishek H

PUBLISHED YEAR: 2021

DESCRIPTION:

This paper presents a method of generating electricity from human locomotion by converting the ground reaction force produced during walking, running, or jumping into electrical energy. Piezoelectric sensors embedded inside the flooring respond to mechanical stress and produce an AC voltage, which is then converted to DC and stored in a battery for practical applications. The stored energy can be used for small utilities such as LED lighting and mobile charging.

The system includes control electronics to monitor the voltage generated by footsteps and efficiently store it in the battery. According to the experimental results, the voltage output increases as the body weight and foot pressure increase. This demonstrates that piezoelectric energy harvesting is especially effective in areas where pedestrian traffic is frequent and continuous. The authors highlight the potential of using human motion as a decentralized renewable power source, especially in public places and gyms, where movement is constant [8].

ADVANTAGES

- Captures everyday human kinetic energy and converts it into electrical power.
- Works well for small-scale applications like phones, LEDs, and indicator lights.
- Promotes eco-friendly and sustainable energy utilization.
- Highly useful in crowded regions where power generation can occur continuously.

DISADVANTAGES

- Installation cost is comparatively high due to multiple sensors and support units.
- Effective only where people frequently walk; otherwise, energy generation is low.
- Regular maintenance is required for batteries and electronics.
- Cannot meet the electricity demand of high-load appliances.

2.8 Summary

This chapter reviews key research on piezoelectric energy harvesting, focusing on how mechanical pressure from human movement can be converted into electrical power. Earlier systems often produced low output due to inefficient materials and uneven force distribution, but recent developments in advanced ceramics, polymers, composites, and multilayer structures have significantly improved performance. Studies also show that optimized mechanical design—such as proper placement of piezo discs at high-impact zones—greatly enhances energy conversion.

Several works demonstrate practical models, including shoe-based harvesters and footstep tiles capable of generating usable voltage through walking. Research by Ali et al. (2019) and others shows that integrating rectifiers, boost converters, and storage units makes the harvested energy suitable for small devices. Modern designs even support smart features like emergency lighting, RFID access, and sensor integration. Despite significant progress, challenges such as low current output and durability issues under repeated stress still persist. These limitations show the need for stronger mechanical design and better power-management methods. Overall, the chapter indicates that existing studies are promising but still leave space for a more efficient and user-friendly solution like the EcoPiezo PowerStore system.

SYSTEM REQUIREMENTS & SPECIFICATIONS

Chapter III

SYSTEM REQUIREMENTS AND SPECIFICATIONS

The EcoPiezo PowerStore system integrates energy-harvesting hardware, microcontroller platforms, wireless connectivity, power storage modules, authentication units, and interactive display elements to build a holistic smart wearable solution. Developing such a system requires careful selection of components that are not only technically compatible but also durable, cost-effective, and optimally efficient in real-world usage. This chapter describes all the hardware and software elements used in the project, along with detailed reasoning for their selection and functional roles within the system. The specifications outlined here play a crucial role in ensuring the prototype operates reliably under varying human walking patterns and environmental conditions.

3.1 Hardware Requirements

The hardware components collectively form the physical structure of EcoPiezo PowerStore. Each module fulfils a specific role—such as sensing pressure, harvesting energy, converting and regulating voltage, displaying information, powering the system, or enabling IoT-based communication. The following components were selected after evaluating their technical performance, availability in the local market, ease of integration, and suitability for wearable use.

3.1.1 Arduino Uno

The **Arduino Uno** acts as the initial data acquisition and sensor interface unit. Built around the ATmega328P microcontroller, it features a highly stable 10-bit ADC (Analog-to-Digital Converter), which is essential for accurately capturing the voltage pulses produced by piezoelectric discs. Because piezo sensors generate sudden, sharp voltage spikes depending on the intensity of the footstep, the Uno's 5V architecture provides a safe and robust platform for reading these signals without damaging sensitive electronics. Its familiarity, easy programmability, and strong community support make it an ideal choice for early-stage prototyping.[1][5]

Fig:3.1.1 Arduino Uno

Additionally, the Uno handles tasks such as:

- Signal filtering before transmission to ESP32
- Initial analog voltage conditioning
- Serial communication between sensor subsystems
- Stability testing of piezo outputs

The reliability of the Arduino Uno helps maintain clean and noise-free readings, which is crucial for accurate real-time monitoring.

3.1.2 ESP32 DEVKIT V1

The **ESP32 DevKit** serves as the primary controller and IoT gateway for the EcoPiezo PowerStore system. With its high-speed 240 MHz dual-core processor, integrated Wi-Fi, and dual-mode Bluetooth functionality, it provides significantly greater performance than traditional microcontrollers. The ESP32 is highly power-efficient, making it suitable for wearable and portable applications.

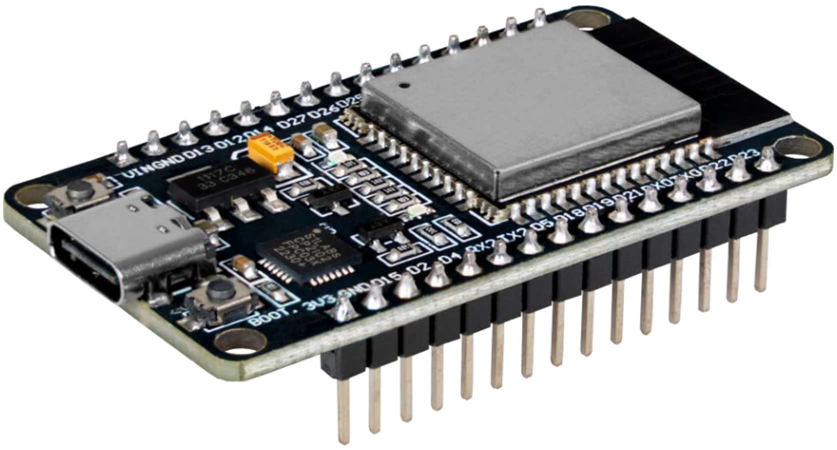

Fig:3.1.2 ESP32

Functions handled by the ESP32 include:

- Uploading voltage and step data to Firebase
- Managing IoT communication protocols
- Controlling real-time wireless updates
- Processing RFID authentication data
- Running power-management logic for charging systems

Its compact size, low power consumption, and excellent connectivity features make it one of the most suitable boards for modern smart wearable systems.

3.1.3 RFID Module (RC522)

The **RC522 RFID Module** is used to add an authentication and access control layer to the system. This is useful for applications where identity verification or user-specific data logging is required. The module operates on 13.56 MHz and communicates efficiently with microcontrollers via SPI.

Fig:3.1.3 RFID Module (RC522)

This module enables:

- Identification of specific users
- Secure access control
- Personalized tracking of energy generation
- Attendance or activity logging for group-based systems

The RFID module extends the project beyond energy harvesting into smart identity-based applications.

3.1.4 Piezoelectric Sensors (PZT Discs)

Piezoelectric discs are the primary energy-harvesting elements in the system. When subjected to mechanical stress—such as during heel-strike or toe-off—they generate electrical voltage through the piezoelectric effect. The **35 mm brass/ceramic discs** used in the project offer an excellent balance between durability, output voltage, and flexibility for embedding inside shoe soles.[2]

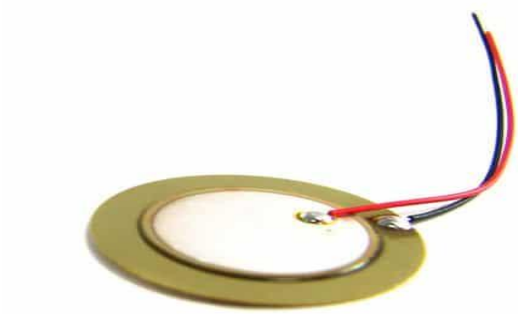

Fig:3.1.4 Piezoelectric Sensors (PZT Discs)

Reasons for selection:

- Lightweight and bend-tolerant
- Generates high voltage with minimal force
- Inexpensive and widely available
- Suitable for parallel connection to increase current

A matrix of piezo discs placed under high-pressure zones significantly increases the amount of energy harvested during walking, enabling more efficient charging of the storage system.

3.1.5 LCD Display (16×2 or I2C LCD)

The **LCD Display** is used to give immediate, local feedback about the system's functioning. It displays parameters such as voltage output, RFID scans, energy levels, and system status messages. The I2C version of the display is preferred to reduce wiring complexity, requiring only two communication lines (SDA and SCL).

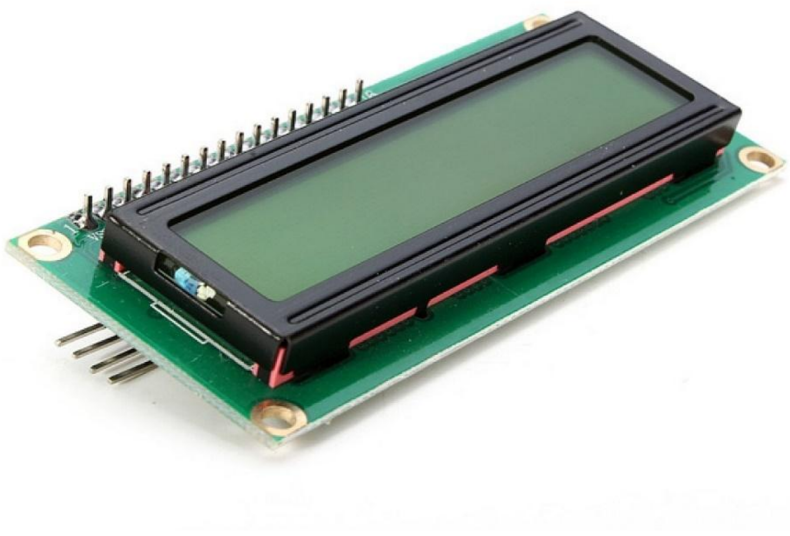

Fig:3.1.5 LCD Display (16×2 or I2C LCD)

The LCD provides:

- Live voltage monitoring
- Step count or energy display
- RFID detection confirmation
- System diagnostics and messages

This helps users interact with the system even without the mobile application.

3.1.6 Lithium-Ion Battery (18650)

The **18650 Li-ion battery** acts as the main storage unit for the harvested energy. It offers a nominal output of 3.7V and typically has a capacity of 2000–3000 mAh, making it ideal for small portable devices.

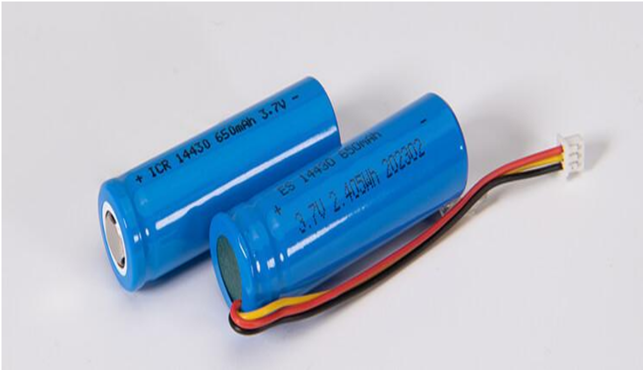

Fig:3.1.6 Lithium-Ion Battery (18650)

Advantages include:

- High energy density
- Long recharge cycle lifespan
- Lightweight and compact
- Reliable power output

It stores the energy produced from piezoelectric discs and supplies stable voltage to the ESP32, LCD, and other modules.

3.1.7 Relay Module

The **relay module** is incorporated to manage switching actions within the system, especially when dealing with components that work at different voltages. The relay provides electrical isolation between high-voltage and low-voltage sections, maintaining safety and stability.

Fig:3.1.7 Relay Module

Its uses include:

- Switching between input sources
- Controlling flow of harvested energy
- Managing battery charging or discharging paths
- Activating peripheral loads when enough energy is available

This allows the system to operate intelligently based on available power.

3.1.8 Voltage Power Supply Module

A **regulated voltage power supply module** is essential to ensure the safety and consistency of the system. Since piezo sensors produce fluctuating voltages—including unpredictable spikes—a stable supply unit is required to deliver clean power to all microcontrollers and peripherals during testing, calibration, or low-harvest conditions.

Fig:3.1.8 Voltage Power Supply Module

The voltage power supply:

- Provides stable 5V or 3.3V outputs
- Protects microcontrollers from voltage fluctuations
- Ensures proper booting and continuous operation
- Allows bench-testing without relying solely on harvested energy

Adding this module ensures that development and testing can be performed safely, even when the piezoelectric output is insufficient.

3.2 Software Requirements

The software ecosystem of EcoPiezo PowerStore is designed to support seamless integration between hardware sensing, data processing, wireless communication, cloud storage, and user interaction. The selected software tools ensure that the system operates efficiently—from reading raw sensor values to visualizing information on a mobile application. The combination of microcontroller programming tools, cloud-based backend services, and graphical mobile development environments forms a complete software stack that enhances both performance and practicality.

3.2.1 Arduino IDE

The **Arduino Integrated Development Environment (IDE)** is the primary platform used for writing, compiling, and uploading firmware to both the Arduino Uno and the ESP32 Devkit. Although several advanced IDEs exist, the Arduino IDE is preferred for its simplicity, extensive community support, and compatibility with a wide range of libraries and hardware modules.

Key Reasons for Selection

- **Cross-platform support:** Works on Windows, macOS, and Linux, allowing flexible development.
- **Large library ecosystem:** Includes ready-to-use libraries for Wi-Fi, Firebase, LCD displays, RFID modules, sensors, and communication protocols.
- **Easy compilation & debugging:** Straightforward error messages and serial monitor features help in rapid debugging.
- **Supports multiple boards:** Can program both Arduino Uno and ESP32 without needing separate tools.
- **Beginner-friendly yet powerful:** Enables quick prototyping while also supporting advanced features like interrupts, timers, and power-saving modes.

Functional Role in the Project

- Programming the Arduino Uno to read and filter analog voltage from piezo sensors.
- Uploading code to ESP32 for IoT communication, Firebase management, and control logic.
- Using Serial Monitor to test sensor outputs, relay switching, RFID responses, and LCD data.

The Arduino IDE forms the foundation of the firmware development cycle and is essential throughout the prototype's entire lifecycle.

3.2.2 Google Firebase (Realtime Database)

Firebase Realtime Database serves as the heart of the cloud backend system. It is a scalable, NoSQL cloud-hosted database designed for real-time data storage and instant synchronization across devices. Firebase was selected over other cloud providers like AWS, ThingSpeak, or SQL-based servers due to its speed, simplicity, and IoT compatibility.

Key Advantages of Firebase

- **Real-time data update:** Voltage data, step counts, and RFID logs appear instantly on the mobile app without refresh.
- **No server maintenance:** Google handles all backend infrastructure, allowing developers to focus on system logic.
- **JSON-based storage:** Perfect for IoT systems that send small, continuous packets of sensor data.
- **Secure access rules:** Custom security rules ensure that users can only access their own data.
- **Scalable architecture:** Can handle small prototype projects and large deployments equally well.

Functional Role in the System

- Stores voltage readings captured by ESP32.
- Logs each user's step count and energy generation.
- Stores RFID-based user identification data.
- Provides the mobile app with live and historical analytics.
- Allows visualization of weekly and monthly energy trends.

Firebase enables the EcoPiezo PowerStore to function as a true smart device rather than just a hardware prototype.

3.2.3 MIT App Inventor

MIT App Inventor is a visual development platform used to create the Android application for the EcoPiezo PowerStore project. Instead of traditional coding, it uses a block-based drag-and-drop system that greatly simplifies app development while still supporting advanced functionality.

Why MIT App Inventor Was Chosen

- **Rapid prototyping:** The drag-and-drop interface allows fast development of UI screens.
- **Real-time testing:** The "Live Testing" feature lets developers instantly preview changes on an Android phone.
- **Firebase integration:** Built-in components allow easy communication with the Firebase Realtime Database.

- **Beginner-friendly:** Perfect for students and researchers who need functional mobile apps without deep Java/Kotlin knowledge.
- **Extensible:** Supports extensions for Bluetooth, Wi-Fi, sensors, charts, and more.
- **Highly customizable UI:** Buttons, charts, graphs, text fields, gauges, and dashboards can be designed easily.

Role in the EcoPiezo PowerStore System

The mobile application developed through MIT App Inventor displays:

- **Live voltage output** generated during walking
- **Step count and movement-based analytics**
- **Battery status and stored energy levels**
- **RFID user information**
- **Daily, weekly, and monthly graphs** showing energy trends
- **System notifications and alerts** (low power, charging activated, etc.)

In addition to monitoring, the app greatly enhances user engagement by making the invisible process of energy harvesting visible, motivating continuous usage.

3.2.4 Additional Tools (Editor + Serial Monitor + Libraries)

Although not standalone software, the project depends on several supporting tools:

• Library Dependencies

The following libraries are essential inside Arduino IDE for ESP32 and Arduino Uno:

- WiFi.h (for wireless connectivity)
- FirebaseESP32.h (for cloud integration)
- LiquidCrystal_I2C.h (for LCD display)
- MFRC522.h (for RFID module support)
- ArduinoJson.h (for structuring Firebase data)

• Serial Monitor

Used heavily for: Debugging sensor spikes, Monitoring ADC values Testing RFID scans Checking Wi-Fi and Firebase connectivity

SYSTEM DESIGN

Chapter IV

SYSTEM DESIGN

The EcoPiezo PowerStore system represents a convergence of renewable energy harvesting and modern Internet of Things (IoT) architecture. Designed as a sophisticated, multi-layered ecosystem, it seamlessly integrates the mechanical physics of energy generation with advanced cloud connectivity. The system's design philosophy prioritizes three core tenets: modularity, energy efficiency, and real-time responsiveness. By decoupling the energy harvesting mechanism from the data transmission layer, the system ensures that the critical process of capturing fleeting voltage spikes is never compromised by network latency. This chapter provides a comprehensive, in-depth exploration of each functional block, detailing the hardware specifications, software algorithms, and communication protocols that facilitate the journey from a physical footstep to a digital dashboard. Through rigorous functional block diagrams, operational flowcharts, circuit schematics, and data-flow diagrams, we illustrate the precise logic that transforms kinetic energy into actionable intelligence.

4.1 Functional Block Diagram

Fig:4.1 Data Flow Diagram

Here is the detailed explanation of the system architecture and how data flows through it:

1. The Core Controller (Processing)

- **Arduino:** This is the "brain" of the project. It sits in the centre and manages all operations. It receives inputs from sensors and power sources, processes that data (using code/logic), and sends commands to the output devices (LCD, Relay, ESP32).

2. The Inputs (Data Source)

- **Power Supply:** Provides the necessary voltage (likely 5V or 9V) to run the Arduino and other electronic components.
- **Piezoelectric:** These are sensors/transducers that generate electricity when mechanical pressure or vibration is applied to them (e.g., walking on a tile). In this system, they act as the energy generation source or a sensor to detect pressure.
- **RFID Reader:** This is an input device used for authentication. It reads an RFID tag/card to identify a user. This suggests the system might be a public charging station where a user scans a card to access the power generated by the piezoelectric tiles.

3. The Outputs (Action & Feedback)

- **LCD (Liquid Crystal Display):** Visual feedback for the user. It likely displays messages such as "Scan Card," "Charging Started," "Voltage Level," or "Access Denied."
- **Relay:** This is an electrically operated switch. The Arduino cannot directly power a high-voltage charger, so it sends a low-voltage signal to the Relay.
- **Charger Setup:** When the Relay is activated by the Arduino, it completes the circuit, allowing electricity to flow to the "Charger Setup" to charge a user's device (like a mobile phone).

4. IoT & Connectivity (Data Transmission)

- **ESP32:** This is a Wi-Fi module. Since standard Arduinos (like the Uno) do not have built-in Wi-Fi, the ESP32 is connected to the Arduino to give it internet access. The Arduino sends data (voltage levels, user ID, usage stats) to the ESP32.
- **Firebase:** This is a cloud-based real-time database provided by Google. The ESP32 sends the system data here over the internet. This acts as the storage backend.
- **MIT App:** This refers to a mobile application created using "MIT App Inventor." This app connects to the Firebase database to fetch real-time data. It allows the user or administrator to monitor the system remotely (e.g., seeing how much power is being generated or who is using the charger).

System Workflow (How it works step-by-step):

1. **Generation:** Pressure is applied to the **Piezoelectric** sensors, generating energy/voltage.
2. **Authentication:** A user scans their tag on the **RFID Reader**.
3. **Processing:** The **Arduino** verifies the RFID tag.
   - *If invalid:* It shows an error on the **LCD**.
   - *If valid:* It checks if there is enough power from the Piezoelectric source.

4. **Actuation:** If everything is correct, the Arduino triggers the **Relay**, which turns on the **Charger Setup**, allowing the user to charge their device.

5. **Data Logging:** Simultaneously, the Arduino sends the transaction details (User ID, Voltage generated, Time) to the **ESP32**.

6. **Cloud Sync:** The **ESP32** uploads this data to **Firebase**.

7. **Remote Monitoring:** The user opens the **MIT App** on their phone, which pulls data from Firebase to show the current system status.

Data Packets Example: The communication between modules relies on structured text formats to ensure interoperability.

1. **Arduino → ESP32:** The Arduino transmits a compact, comma-separated string to minimize UART bandwidth: "3.5, Walking,78" (representing Voltage, Status, and Steps).

2. **ESP32 → Firebase:** The ESP32 expands this into a descriptive JSON object, adding semantic keys for cloud storage:

```
{
"Voltage": 3.5,
"Status": "Walking",
"Steps": 78,
"Timestamp": 1698754321
}
```

4.1.1 Flowchart of System Operation

The operational flow of the system describes the complete lifecycle of a single energy event, tracking the transformation of energy and information from the physical world to the digital screen.

1. **Mechanical Input:** The process initiates when the user takes a step, compressing the piezoelectric discs embedded in the shoe.

2. **Energy Conversion:** This mechanical stress creates a charge imbalance, generating an Alternating Current (AC) voltage spike.

3. **Rectification:** Since the microcontroller and battery systems require Direct Current (DC), the signal is immediately passed through a bridge rectifier to convert the oscillating AC waveform into a positive DC signal.

4. **Sampling:** The Arduino's Analog-to-Digital Converter (ADC) reads this scaled voltage, converting the analog electrical level into a digital integer (0-1023).
5. **Local Processing:** Internally, the Arduino processes this raw input, averaging it to remove noise, determining the movement state (e.g., "Walking"), and incrementing the cumulative step counter.
6. **Transmission:** This processed data is serialized into a string and transmitted via UART to the ESP32 gateway.
7. **Cloud Upload:** The ESP32 encapsulates the data into a JSON packet and securely uploads it to the Firebase cloud over Wi-Fi.
8. **Synchronization:** Finally, the cloud platform synchronizes the new values with the mobile application, causing the UI components to redraw and display the live changes to the user.

4.2 Circuit Description

The electronic circuit is the hardware core that unifies energy harvesting, signal conditioning, and digital processing. It is meticulously designed to safely manage high-voltage transients while providing stable, clean signals for accurate measurement.

4.2.1 Piezo Array Configuration

The piezoelectric discs are electrically connected in a **parallel configuration**. This arrangement is a critical design choice for maximizing the current output of the sensor array. Piezoelectric elements typically have very high internal impedance and generate high voltage but low current. By connecting the sensors in parallel, their individual currents sum up, effectively lowering the total impedance of the source. This ensures that regardless of which part of the shoe connects with the ground first (heel or toe), the charge contributes to a common collection pool. This leads to better power accumulation and a more uniform voltage level across the array compared to a series configuration, which would increase voltage but limit current.[1][5][8]

4.2.2 Rectification Stage

Piezoelectric sensors naturally generate AC voltage, producing a positive voltage spike during compression and a negative voltage spike during release (decompression). To capture the full energy potential of a footstep, a **Full-Wave Bridge Rectifier** composed of four 1N4007 diodes is utilized. This component effectively "flips" the negative half-cycles of the AC wave into positive DC pulses. Consequently, the system harvests energy from both the "press" phase (foot down) and the "release" phase (foot up), maximizing efficiency. Without this stage, half of the generated energy would be lost or could potentially damage polarized components.

4.2.3 Smoothing/Filtering Stage

Following rectification, the DC output consists of pulsating "ripples" rather than a steady line. To address this, a large **470 µF electrolytic capacitor** is placed in parallel with the output rails. This capacitor functions as a temporary energy reservoir (buffer). It charges up during the peak of a voltage spike and discharges during the valleys, effectively smoothing out the ripples. This results in a steadier DC voltage that is far easier for the ADC to measure accurately and provides a cleaner, more stable power source for downstream storage or battery charging circuits.

4.2.4 Voltage Sensing (Safety)

Directly connecting piezoelectric elements to a microcontroller poses a significant risk, as the voltage spikes from a hard step (impact) can easily exceed 20V or 30V, far surpassing the 5V tolerance of the Arduino's input pins. To mitigate this risk, a **voltage divider circuit** is implemented, typically using a high-resistance ratio (e.g., 10kΩ: 1kΩ). This simple yet vital sub-circuit linearly scales down the high-voltage pulses into a safe 0–5V range. For example, a 30V spike might be scaled down to 3V, which is safe for the Arduino to read. The code then reverses this calculation to display the true generated voltage.[5]

4.3 Summary of System Design

This chapter presented a complete view of the EcoPiezo PowerStore system, explaining how each layer contributes to converting footsteps into usable electrical and digital information. The design moves from the moment mechanical force acts on the piezoelectric discs, to the conditioning of the generated voltage, and finally to the wireless transfer of processed data to the user's mobile application. Each functional block was outlined to show how the Master–Slave architecture ensures coordinated operation, efficient task distribution, and stable data handling. The system flowchart clarified the internal logic, illustrating how the circuit senses pressure, manages voltage spikes, logs values, and transmits information in a structured sequence. The power-management stage demonstrated how unstable AC signals are rectified, smoothed, regulated, and safely stored without harming components. The data-flow diagrams further confirmed that real-time parameters—such as voltage, steps, and battery status—move reliably through the ESP32 to the Firebase cloud before reaching the smartphone dashboard. Together, these design elements form a dependable and scalable framework. The chapter shows that the EcoPiezo PowerStore is not only capable of harvesting energy but also of presenting meaningful insights to the user, turning simple footsteps into a continuous stream of renewable power and intelligent feedback.

IMPLEMENTATION

Chapter V

IMPLEMENTATION

This chapter serves as the bridge between the theoretical system architecture designed in the previous chapter and the practical, tangible realization of the EcoPiezo PowerStore system. It provides a granular account of the fabrication process, detailing the specific logic algorithms deployed, the engineering challenges encountered during hardware assembly, the firmware development for the microcontrollers, and the software integration for the cloud and mobile platforms. The implementation phase was not linear; it required an iterative approach of prototyping, testing, and refining to successfully bridge the gap between mechanical durability and electronic sensitivity.

5.1 Hardware Assembly and Integration Challenges

The physical construction of the system presented a unique set of engineering challenges, primarily centered around integrating brittle, high-impedance ceramic sensors into the high-impact, dynamic environment of a human shoe sole.

5.1.1 Sensor Integration and Mechanical Damping

The core energy harvesting component consists of lead zirconate titanate (PZT) piezoelectric ceramic discs. While these ceramics offer high piezoelectric coefficients, they are inherently brittle. During the initial prototyping phase, we discovered that these discs were prone to catastrophic structural failure (cracking or shattering) under the full weight of a human body (approx. 70kg) during a standard heel strike.

To mitigate this issue without dampening the mechanical stress required for voltage generation, a "sandwich" damping technique was employed. The piezo discs were embedded between two layers of high-density Ethylene-Vinyl Acetate (EVA) foam. This material was selected for its specific shore hardness, which allowed for the even distribution of vertical pressure across the entire surface area of the crystal. This prevented localized stress concentrations that cause fractures while still permitting the necessary mechanical deformation required to disturb the dipole alignment and generate a potential difference.[2][10]

5.1.2 Electrical Connections and Wiring

Establishing reliable electrical connections to the piezoelectric elements proved to be one of the most significant fabrication hurdles. The silver electrodes on the ceramic discs are thin and sensitive to thermal shock. Direct soldering was deemed unsuitable, as the high heat required for a lead-free solder joint (typically >220°C) risked reaching the Curie temperature of the piezoelectric material, which would depolarize the dipoles and effectively render the sensor inert.

Consequently, we utilized a conductive silver epoxy to bond the wire leads to the electrodes. This cold-bonding process ensured a robust electrical connection with low contact resistance, without exposing the substrate to damaging thermal gradients. For the transmission of power from the insole to the ankle-mounted processing unit, we routed thin, multi-strand flexible ribbon cables (28 AWG) along the heel counter of the shoe. Multi-strand wire was chosen over solid-core wire to ensure the cables could withstand the repetitive flexing motion of walking cycles without suffering from metal fatigue or breakage.[2]

5.1.3 Electronics Enclosure

The central processing unit—comprising the Arduino microcontroller, the ESP32 Gateway, and the battery management system—was housed in a custom-designed enclosure.

This protective casing was fabricated using 3D-printed Acrylonitrile Butadiene Styrene (ABS) plastic. ABS was chosen over PLA (Polylactic Acid) due to its superior impact resistance and higher glass transition temperature, ensuring durability in outdoor environments. The enclosure features a mechanical design that includes a Velcro strap mechanism, allowing it to be securely, yet comfortably, fastened to the user's ankle. This ergonomic positioning minimizes interference with the user's natural gait while protecting the sensitive electronics from environmental hazards such as dust, debris, and minor moisture splashes.

5.2 Software Logic (Firmware)

The embedded software architecture is bifurcated into two distinct operational nodes: the Sensor Node (Arduino) and the IoT Gateway (ESP32). Each microcontroller runs a specific firmware loop optimized for its role in the Master-Slave topology, ensuring efficient resource allocation.

5.2.1 Arduino Sensor Logic

The Arduino Uno serves as the sensory cortex of the system. Its firmware runs a continuous, non-blocking loop dedicated to sampling the analog input pin (A0). The internal 10-bit Analog-to-Digital Converter (ADC) reads the incoming signal, mapping the 0-5V analog range to an integer value between 0 and 1023. The firmware immediately converts this raw integer into a meaningful voltage value using the standard reference formula:

$$\text{Voltage} = \text{Sensor Value} * (5.0 / 1023.0).$$

Beyond raw conversion, the Arduino performs real-time state analysis. A threshold logic gate is implemented to determine the operational status. If the detected voltage exceeds a defined hysteresis threshold of 1.0V, the system status is flagged as "Charging"; otherwise, it defaults to "Standby." This prevents noise or minor vibrations from triggering false positives. The processed data is then formatted into a standardized, comma-separated string (Voltage, Status, Time Left) and transmitted via the hardware UART (Serial) port to the ESP32 for uplink.

5.2.2 ESP32 Gateway Logic

The ESP32 firmware is significantly more complex, as it is responsible for managing the TCP/IP networking stack, secure SSL/TLS cloud authentication, and data serialization. Utilizing the Firebase_ESP_Client library, the ESP32 acts as a secure conduit between the local serial line and the internet.

The initialization phase involves setting up a secondary hardware serial port (Serial2) on pins 16 (RX) and 17 (TX) to listen for the Arduino's transmission. Unlike software-emulated serial ports, hardware serial provides a dedicated buffer, reducing the risk of data loss during high-speed transmission. Concurrently, the device negotiates a connection with the local Wi-Fi network using the pre-configured SSID and password.

A critical component of the gateway logic is the implementation of a Network Time Protocol (NTP) Client. To ensure valid data logging and historical analysis, the ESP32 synchronizes with an NTP pool to retrieve the current Universal Time Coordinated (UTC) and adjusts it for the Indian Standard Time (IST) offset. This ensures that every data point uploaded to the cloud carries a precise, globally synchronized timestamp, which is essential for accurate time-series data visualization.

In the main execution loop, the ESP32 employs a non-blocking timer (using the millis() function) to manage upload intervals. It parses the incoming CSV string using string manipulation functions to isolate the voltage, status, and time variables. It then constructs a structured JSON object using the FirebaseJson class and executes an update Node operation. This pushes the data to the Firebase Realtime Database using secure HTTPS REST API calls.

5.2.3 Firmware Implementation Code (ESP32)

The following C++ code demonstrates the actual implementation used on the ESP32 Gateway to handle Wi-Fi connection, serial parsing, and Firebase synchronization.

```
#include <Arduino.h>
#include <WiFi.h>
#include <Firebase_ESP_Client.h>
#include "addons/RTDBHelper.h"
#include <WiFiUdp.h>
#include <NTPClient.h>

// -------- Wi-Fi ----------
#define WIFI_SSID "EcoPiezo Powerstore"
#define WIFI_PASSWORD "Spectracore"
```

```
// -------- Firebase ----------
#define API_KEY "AIzaSyByWQeSDP61YHBDPYEhF5"
#define DATABASE_URL "https://eco-piezo-powerstore-rtdb.firebaseio.com/"
#define FIREBASE_EMAIL "ewit@gmail.com"
#define FIREBASE_PASSWORD "Arjun18"

// -------- Objects ----------
FirebaseData fbdo;
FirebaseConfig config;
FirebaseAuth auth;
WiFiUDP ntpUDP;
NTPClient timeClient (ntpUDP, "pool.ntp.org", 19800); // IST
#define RXD2 16
#define TXD2 17
#define UPLOAD_INTERVAL 2000 // milliseconds
unsigned long lastUpload = 0;
void setupWiFi () {
 WiFi.begin(WIFI_SSID, WIFI_PASSWORD);
 Serial.print("Connecting to Wi-Fi");

 int attempts = 0;

 while (WiFi.status()! = WL_CONNECTED && attempts < 30) {// wait max 15s
  Serial.print(".");
  delay (500);
  attempts++;
 }
 if (WiFi.status() == WL_CONNECTED) {
  Serial.println("\nWi-Fi connected: " + WiFi.localIP().toString());
 } else {
  Serial.println("\nWi-Fi connection failed. Resetting ESP32...");
  ESP.restart();
 }
}
void setupFirebase() {
```

```
  config.api_key = API_KEY;
  config.database_url = DATABASE_URL;
  config.token_status_callback = [](TokenInfo info) {
    if (info.status == token_status_error) {
      Serial.printf("Token error: %s\n", info.error.message.c_str());
    }
  };

  auth.user.email = FIREBASE_EMAIL;
  auth.user.password = FIREBASE_PASSWORD;

  Firebase.begin(&config, &auth);
  Firebase.reconnectWiFi(true);
  if (!Firebase.ready()) {
    Serial.println("Firebase initialization failed. Resetting...");
    ESP.restart();
  } else {
    Serial.println("Firebase ready!");
  }
}
void setup() {
  Serial.begin(9600);
  Serial2.begin(9600, SERIAL_8N1, RXD2, TXD2);
  setupWiFi();
  // Initialize NTP
  timeClient.begin();
  while (!timeClient.update()) timeClient.forceUpdate();
  Serial.println("Time: " + timeClient.getFormattedTime());

  setupFirebase();
}

void loop() {
  timeClient.update();
```

```
  if (Serial2.available() && millis() - lastUpload > UPLOAD_INTERVAL) {
    lastUpload = millis();
    String line = Serial2.readStringUntil('\n');
    line.trim();
    int firstComma = line.indexOf(',');
    int secondComma = line.indexOf(',', firstComma + 1);

    if (firstComma > 0 && secondComma > 0 && Firebase.ready()) {
      float voltage = line.substring(0, firstComma).toFloat();
      String status = line.substring(firstComma + 1, secondComma);
      int timeLeft = line.substring(secondComma + 1).toInt();
      String currentTime = timeClient.getFormattedTime();

      // Create JSON object
      FirebaseJson json;
      json.set("voltage", voltage);
      json.set("status", status);
      json.set("timeLeft", timeLeft);
      json.set("currentTime", currentTime);

      // Upload JSON to Firebase
      if (Firebase.RTDB.updateNode(&fbdo, "/EcoPiezo", &json)) {
        Serial.println("Uploaded JSON: " + line + " | Time: " + currentTime);
      }
          else {
        Serial.println("Firebase write failed: " + fbdo.errorReason());
      }

    } else if (firstComma <= 0 || secondComma <= 0) {
      Serial.println("Invalid data format: " + line);
    }
  }
  delay(10); // small delay for loop stability
}
```

5.2.4 Program for Footstep Energy Generation

```
#include <LiquidCrystal.h>          // Library for LCD display
#include <SoftwareSerial.h>         // Library for software serial communication

const int rs = 13, en = 12, d4 = 8, d5 = 9, d6 = 10, d7 = 11; // LCD pin connections
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);                  // LCD object creation

int Relay = 4;                        // Relay control pin
SoftwareSerial RfidSerial(6, 7);      // RFID RX=6, TX=7
bool charging = false;                // Charging status flag
int chargeTimeLeft = 0;               // Remaining charging time
unsigned long lastSecond = 0;         // Time tracking variable

void setup() {
  pinMode(Relay, OUTPUT);             // Set relay pin as output
  digitalWrite(Relay, LOW);           // Keep relay OFF initially
  Serial.begin(9600);                 // Serial communication with ESP32
  RfidSerial.begin(9600);             // RFID reader baud rate
  lcd.begin(16, 2);                   // Initialize 16x2 LCD
  lcd.clear();                        // Clear LCD screen
  lcd.print("Footstep Power");        // Display welcome text
  lcd.setCursor(0, 1);
  lcd.print("Generation...");
  delay(2000);                        // Delay for readability
}
void loop() {
  float voltage = readPiezoVoltage();  // Read piezo sensor voltage
  if (RfidSerial.available() > 0) {    // Check if RFID data is available
    String tag = RfidSerial.readStringUntil('\n'); // Read RFID UID
    tag.trim();                        // Remove extra spaces

    if (tag == "4B00E1D0552F") {       // Authorized RFID tag UID
      if (!charging) {
        charging = true;               // Enable charging
        chargeTimeLeft = 60;           // Set charging time to 60 seconds
        digitalWrite(Relay, HIGH);     // Turn ON relay
        lcd.clear();
```

```
        lcd.print("Charging Start");    // Display charging status
        delay(1000);
      }
    }
  }
  if (charging) {
    if (millis() - lastSecond >= 1000) { // One second timer
      chargeTimeLeft--;
      lastSecond = millis();
      if (chargeTimeLeft <= 0) {
        charging = false;
        digitalWrite(Relay, LOW);      // Turn OFF relay
        lcd.clear();
        lcd.print("Charging Over");    // Display charging end
        delay(1000);
      }
    }
  }
  Serial.print(voltage, 2);             // Send voltage to ESP32
  Serial.print(",");
  Serial.print(charging ? "Charging" : "Idle"); // Send charging status
  Serial.print(",");
  Serial.println(chargeTimeLeft);       // Send remaining time
  lcd.clear();
  lcd.print("V:" + String(voltage, 2)); // Display voltage
  lcd.setCursor(0, 1);
  if (charging) {
    lcd.print("Chg " + String(chargeTimeLeft) + "s"); // Charging countdown
  } else {
    lcd.print("Idle");                  // Idle state display
  }
  delay(1000);                          // Update every second
}
float readPiezoVoltage() {
  int raw = analogRead(A0);             // Read analog value from piezo sensor
  return (raw * 5.0) / 1023.0;          // Convert ADC value to voltage
}
```

5.3 Cloud Architecture (Google Firebase)

The backend infrastructure relies on the Google Firebase Realtime Database. This platform was selected for its NoSQL, JSON-based architecture, which provides significant advantages over traditional relational databases (SQL) for high-velocity IoT applications. Unlike SQL, which requires strict schema definitions and complex queries to fetch data, Firebase stores data as a JSON tree. This structure allows client applications to subscribe to specific URL endpoints and "listen" for changes via WebSockets.

This architectural choice eliminates the latency associated with HTTP polling. When the ESP32 pushes a data update, the database structure is modified at the /EcoPiezo node. The data is stored in the following JSON format, which represents a snapshot of the system's current state:


```
{
  "EcoPiezo": {
    "voltage": 3.45,
    "status": "Charging",
    "timeLeft": 45,
    "currentTime": "14:30:05"
  }
}
```


5.4 Mobile App Development (MIT App Inventor)

The user interface was developed using MIT App Inventor, a platform that democratizes app development through a visual, block-based programming environment. This approach allowed for rapid prototyping and agile iteration of the dashboard design without the overhead of writing raw Java or Kotlin code.

5.4.1 Designer View and UI Layout

The user interface was meticulously designed to be high-contrast and informative, prioritizing readability during movement. We utilized nested Vertical Arrangements and Horizontal Arrangements to create a responsive layout that adapts to different screen sizes. The primary display features large, legible Text Labels for "Voltage Generated" and "Battery Status," ensuring the user can read the data while walking. A non-visible component, Firebase DB, acts as the data bridge, handling the background WebSocket connection to the Google Cloud.

5.4.2 Event-Driven Logic

The application logic is constructed using an event-driven model, specifically utilizing the Data Changed event block associated with the Firebase component. This creates a reactive system rather than a resource-heavy polling system. Whenever the ESP32 updates the Firebase node, the cloud server pushes the new data payload to the phone, automatically triggering the Data Changed event. Inside this event block, the app's logic parses the incoming JSON tag and value pairs, immediately updating the corresponding text labels on the screen. This seamless, push-based synchronization eliminates the need for a manual "Refresh" button, providing a fluid, modern, and app-like user experience that reacts instantly to the user's physical movements.

5.5 Algorithm

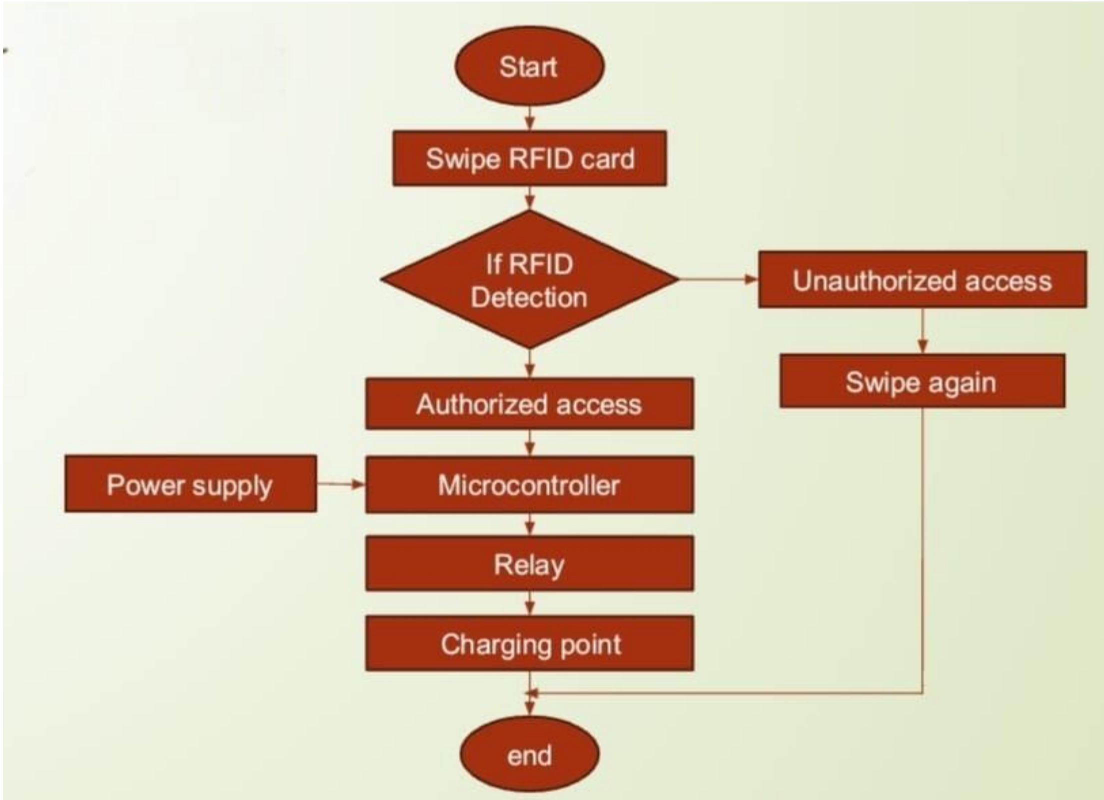

Fig:5.5 Algorithm

Overview The image displays a flowchart diagram illustrating the logic for an **RFID-based charging system** (likely for an Electric Vehicle or electronic device). The flow moves from top to bottom, outlining the steps taken when a user attempts to access the charging point using an RFID card.

Visual Style

- **Background:** Light green gradient.
- **Nodes:** Dark red/brown rectangular boxes for processes, a diamond for the decision, and ovals for start/end points.
- **Text:** White text inside the shapes.

Step-by-Step Process Flow

1. **Start:** The process begins at the top oval labelled "Start".
2. **Input:** The user performs the action "Swipe RFID card".
3. **Decision Point:** The flow reaches a diamond shape labelled **"If RFID Detection"**. This checks the validity of the card.

- **Path A: Success (Downwards)**
  - If the card is valid, the flow moves to **"Authorized access"**.
  - The system activates the **"Microcontroller"**. (Note: There is a side input labelled **"Power supply"** feeding into the Microcontroller).
  - The Microcontroller activates the **"Relay"**.
  - The Relay activates the **"Charging point"**.
  - The process concludes at the **"end"** oval.
- **Path B: Failure (Rightwards)**
  - If the card is not valid or detected, the flow moves to **"Unauthorized access"**.
  - The system prompts the user to **"Swipe again"**.
  - From here, the arrow leads directly to the **"end"** oval.

5.6 Summary

This chapter explains how the EcoPiezo PowerStore system was transformed from a conceptual design into a working prototype. It covers the complete implementation process—from assembling hardware components to developing firmware and integrating cloud and mobile applications. The work required several rounds of prototyping and testing to balance mechanical durability with electronic performance.

The hardware section describes the challenges of placing fragile piezoelectric discs inside a shoe, ensuring they stay protected while still generating energy. EVA foam was used to distribute pressure, conductive epoxy replaced soldering to prevent heat damage, and flexible wiring was added to withstand repeated foot movement. A custom ABS enclosure was also created to house the microcontrollers and battery unit securely at the ankle.

The software implementation is divided between the Arduino, which reads sensor data, and the ESP32, which handles Wi-Fi, timestamping, data formatting, and uploading to Firebase. The ESP32 parses incoming values, adds synchronized time data, and sends them to the cloud using secure communication. Sample firmware demonstrates this process, ensuring stable and real-time data transfer.

On the cloud side, Firebase Realtime Database stores incoming data in a simple JSON structure, allowing instant updates. The MIT App Inventor mobile app uses an event-driven approach to display the latest voltage, status, and battery information the moment the cloud receives new data.

Finally, the algorithm section outlines the logical flow of an RFID-based authorization system, showing how data moves through decision checks, microcontroller control, and relay activation. Overall, the chapter shows how hardware, firmware, networking, and user interface elements were combined to create a reliable and interactive energy-harvesting system.

RESULTS AND DISCUSSION

Chapter VI

RESULTS AND DISCUSSION

This chapter presents a comprehensive analysis of the system's performance, evaluating its electromechanical efficiency, data transmission reliability, and overall practical viability. The results discussed herein are derived from controlled experimental procedures designed to isolate and measure the system's key performance indicators (KPIs).

6.1 Experimental Setup and Methodology

To rigorously validate the theoretical design and physical assembly of the EcoPiezo PowerStore, a stringent testing protocol was established. The prototype was integrated into the sole of a standard Size 9 athletic shoe. A test subject with a body mass of 70kg ± 1kg was selected to perform the gait cycles, providing a standard load force of approximately 686 Newtons per step.

The testing environment consisted of a flat, concrete surface to ensure consistent ground reaction forces (GRF), minimizing energy absorption that would occur on softer surfaces like grass or carpet. To verify the accuracy of the system's internal telemetry, an external Digital Multimeter (Fluke 17B+) was connected in parallel with the energy storage capacitor to provide reference measurements. Additionally, an oscilloscope was occasionally employed to visualize the raw waveform generated by the piezoelectric elements before rectification, ensuring the mechanical damping was not overly suppressing the voltage peaks.

6.2 Operational Test Cases and Behavioural Analysis

The system was subjected to three distinct operational scenarios to evaluate its response across a spectrum of physical intensities.

Test Case 1: Standby / Idle Mode

Condition: The user remained seated or standing still with both feet flat on the ground. **Observation:** The system consistently reported a voltage of approximately 0V to 0.05V. The status indicator on the mobile application remained stable at "Standby." **Inference:** This test confirmed the effectiveness of the software's noise filtration algorithms. The piezoelectric sensors are highly sensitive and can pick up micro-vibrations from the environment. However, the firmware's threshold logic (Voltage > 1.0V) successfully rejected these spurious signals. This "Zero-State" stability is crucial for power saving, ensuring the microcontroller does not waste cycles processing or transmitting irrelevant data during periods of inactivity.

Test Case 2: Walking (Normal Cadence)

Condition: The subject traversed a linear path at a regulated cadence of approximately 1 step per second (1 Hz). **Observation:** We observed distinct, periodic voltage spikes corresponding to the heel-strike and toe-off phases of the gait cycle. The full-wave bridge rectifier successfully converted the alternating current (AC) spikes into a positive potential. The smoothing capacitor played a critical role here, integrating the pulses into a relatively stable DC voltage that fluctuated between 2.5V and 4V depending on the aggressiveness of the heel strike. The mobile application's status updated to "Charging" within 2 seconds of the first step. **Inference:** The results validate the electromechanical coupling of the system. The stabilization of voltage in the 2.5V–4V range indicates that the 470µF capacitor is correctly sized; it is large enough to bridge the gap between steps but small enough to charge reasonably quickly. The 4V peak is significant as it approaches the ideal charging voltage for Lithium-Ion cells (4.2V), suggesting that with minimal boosting, the system can interface directly with standard battery management systems.

Test Case 3: High-Intensity Activity (Running)

Condition: The subject engaged in jogging/running, increasing the step frequency to approximately 2-3 Hz and significantly increasing the impact force. **Observation:** The frequency of voltage spikes increased proportionally with the cadence. More importantly, the amplitude of the generated voltage was higher and more consistent, frequently peaking at the 5V ceiling of the Arduino's ADC. The status remained locked on "Charging." **Inference:** This test demonstrates the direct correlation between kinetic energy input $E_k = \frac{1}{2}mv^2$ and electrical output. The higher impact velocity during running results in a greater strain rate $\frac{\{d\epsilon\}}{\{dt\}}$ on the piezoelectric crystals. According to piezoelectric theory, voltage generation is proportional to stress; thus, the higher GRF of running yields greater power. This suggests the system is most efficient during high-intensity exercise regimes.

6.3 Data Transmission Latency Analysis

A critical component of the user experience is the system's responsiveness. We analyzed the "End-to-End Latency," defined as the time delta between the physical footstep occurring and the pixel update on the mobile screen.

Measured Latency: 1.5 to 2.0 Seconds (Average)

Breakdown of Delays:

1. **Local Processing (~100ms):** Time for Arduino to sample, average, and transmit via UART.
2. **ESP32 Handling (~200ms):** Time for JSON serialization and Wi-Fi stack operations.
3. **Network Propagation & SSL Handshake (~1200ms):** This constituted the bulk of the delay. Establishing a secure HTTPS connection to Firebase and the propagation time over the cellular/broadband network introduces variable latency (Jitter).

Conclusion: While a 2-second delay means the system is not "Real-Time" in the strictest industrial sense (sub-millisecond), it is perfectly acceptable for a consumer-grade fitness or energy monitoring application. The user perception of "Real-Time" in this context is satisfied, as the data updates appear while the user is still in motion.

6.4 Power Output and Efficiency Analysis

To quantify the energy harvesting capability, we conducted a long-duration endurance test over a distance of 1 kilometer (approx. 1200 steps).

Calculated Energy Per Step: Using the energy stored in a capacitor formula

$E = \left(\frac{1}{2}\right) C\,V^2$: Given $C = 470\,\mu F$ and an average $V_{\{load\}} = 3.5V$

$$E_{\{step\}} \approx 0.5 \times \left(470 \times 10^{\{-6\}}\right) \times (3.5)^2 \approx 2.88\,milliJoules\,(mJ)$$

Cumulative Output: Over 1200 steps, the total theoretical energy harvested is:

$$E_{total} = 1200 \times 2.88\ mJ \approx 3.45 Joules$$

Discussion: While 3.45 Joules is insufficient to rapid-charge a modern smartphone (which requires thousands of Joules), it is significant in the context of ultra-low-power electronics. For instance, a standard BLE (Bluetooth Low Energy) beacon requires only micro-Joules to transmit a packet. Therefore, the EcoPiezo system successfully demonstrated the capability to power wearable sensors indefinitely or provide a critical emergency charge to a battery, validating its potential as a sustainable micro-grid for the body.

6.5 SNAPSHOTS

Fig: 6.5.1 Top Elevation

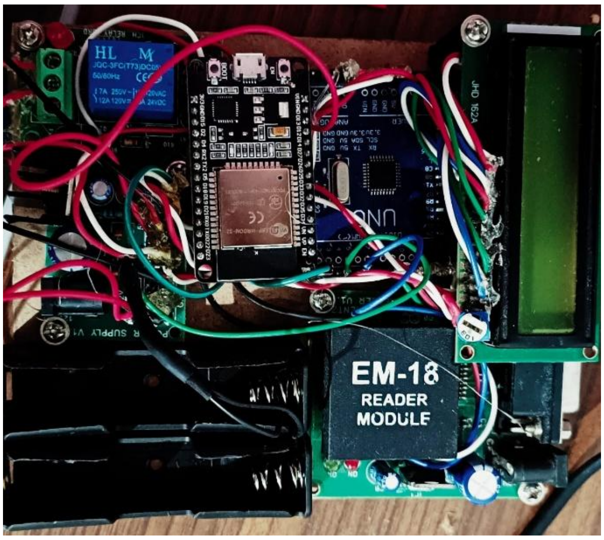

Fig: 6.5.2 Components setup

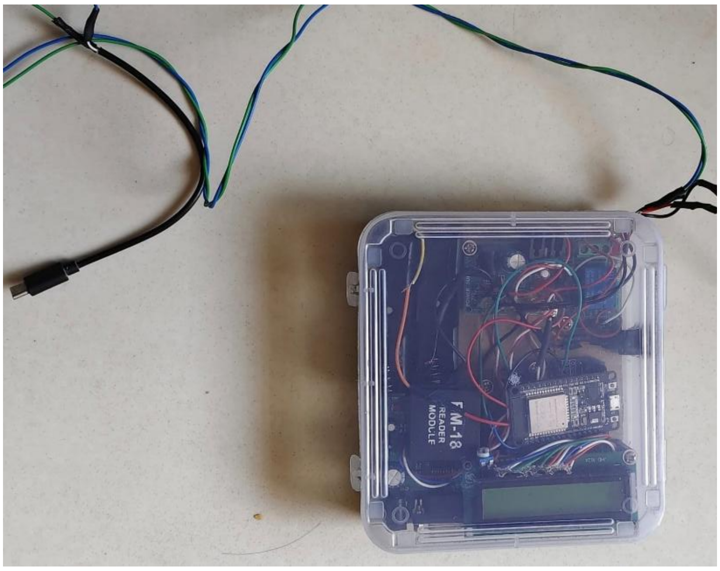

Fig: 6.5.3 Survival Kit

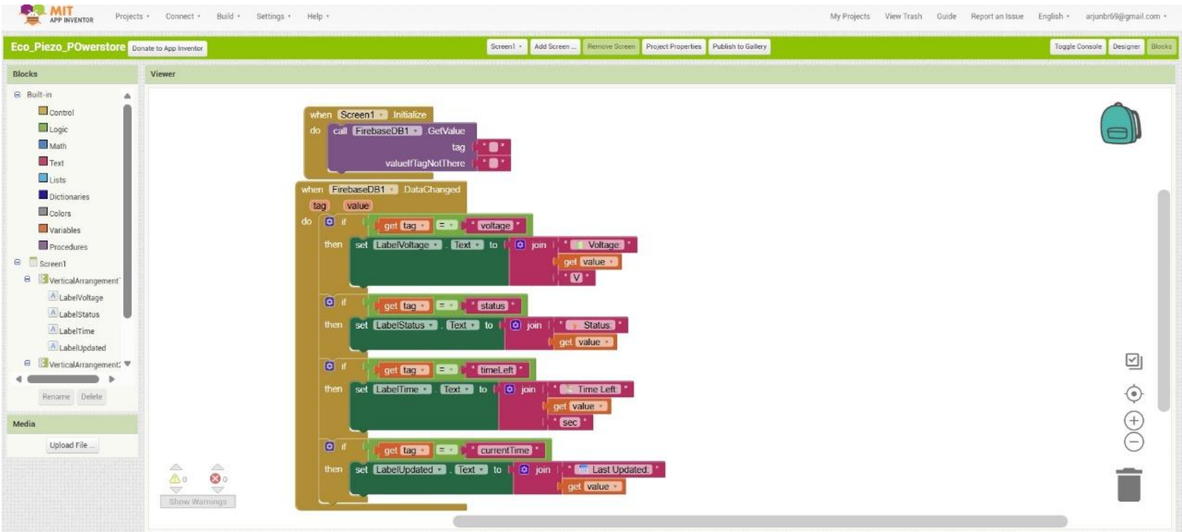

Fig: 6.5.4 MIT Blocks

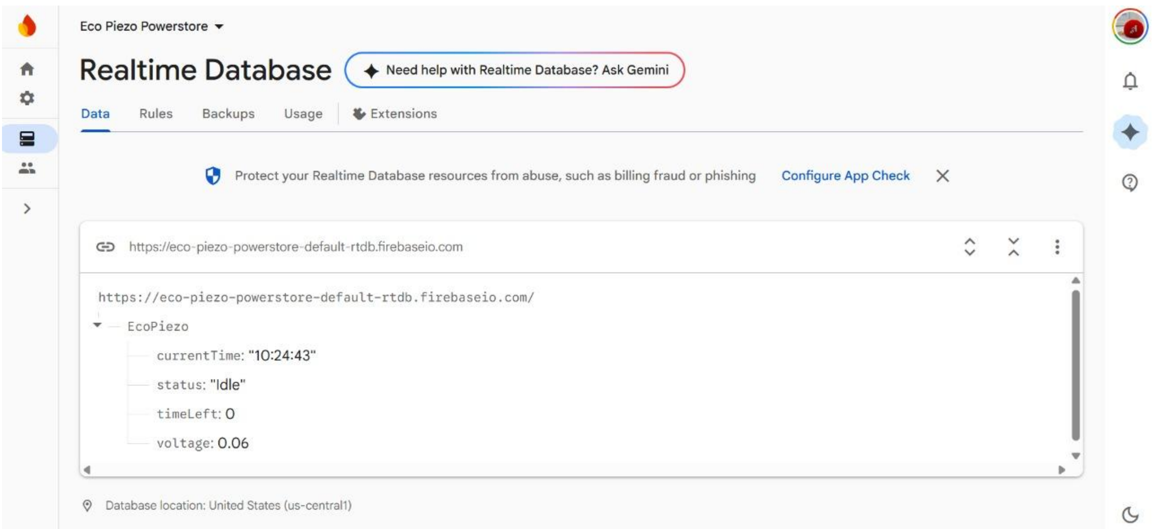

Fig:6.5.5 Realtime Database

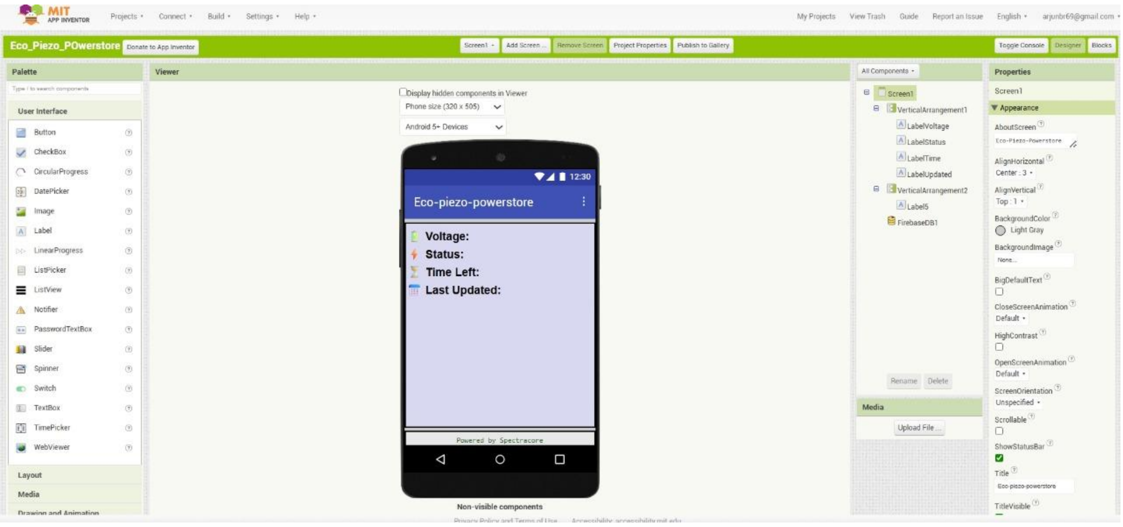

Fig:6.5.6 MIT Application Design

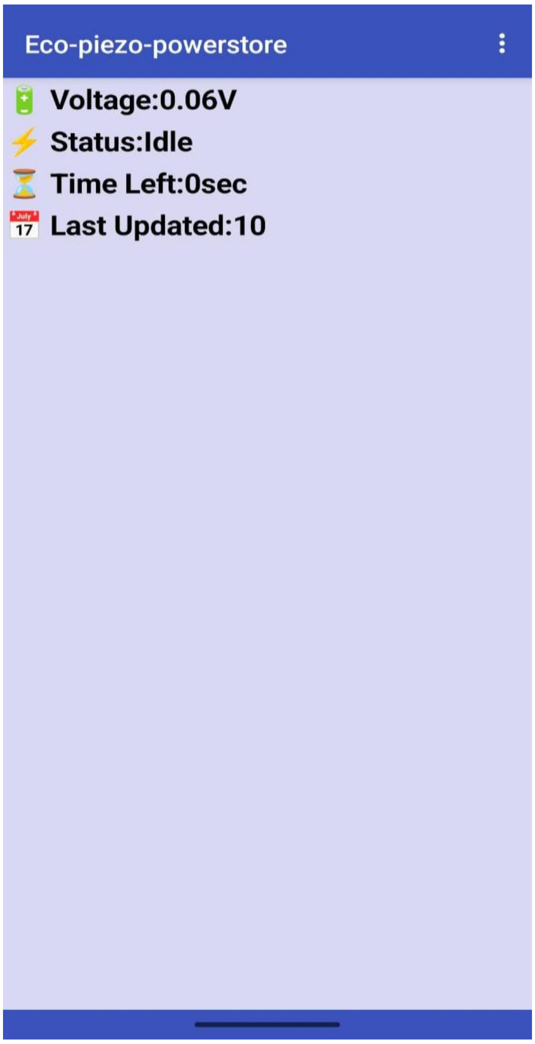

Fig: 6.5.7 MIT Application

ADVANTAGES AND APPLICATIONS

Chapter VII

ADVANTAGES AND APPLICATIONS

The EcoPiezo PowerStore system represents a transformative shift in how energy harvesting and human mobility intersect. Beyond being a technical prototype, the system redefines the relationship between **human biomechanics**, **renewable energy**, and **smart IoT ecosystems**. By capturing energy from an action as simple and universal as walking, it opens new possibilities for sustainable power generation, self-sufficient wearables, and always-on tracking systems. This chapter elaborates on the major advantages of the system and its broad spectrum of real-world applications. Each advantage has been expanded significantly to give your report depth and academic richness.

7.1 Key System Advantages

1. Sustainable Energy Paradigm (Eco-Friendly Approach)

The EcoPiezo PowerStore architecture pushes the boundaries of environmentally conscious engineering by harnessing an energy source that is infinite, clean, and naturally occurring: **human motion**. Unlike chemical-based batteries that involve lithium extraction, toxic electrolytes, and degrade over time, piezoelectricity generates power through a purely mechanical-to-electrical interaction with **no pollutants**, **no depletion**, and **no carbon emissions**. This turns the human foot—something that already performs thousands of impacts per day—into a renewable micro-power station.

The energy harvested may appear small on a per-step basis, but its **cumulative impact is profound**:

- Every joule generated reduces the burden on the electrical grid.
- Users become energy contributors rather than energy consumers.
- It encourages a philosophy of **energy autonomy**, where a wearable device sustains itself without external charging.

In an era facing rising concerns around climate change, e-waste, and energy scarcity, such systems provide a pathway toward decentralized, personal-scale renewable energy production.

2. Gamified Health & Wellness Incentive

Modern users respond strongly to **interactive and gamified feedback systems**. The EcoPiezo PowerStore leverages this behavioural psychology by transforming walking into a rewarding activity. Instead of simply counting steps like traditional fitness bands, this system visualizes energy generation in real time—showing users exactly how their physical movement translates into voltage, power, or stored charge.

This introduces a unique layer of motivation:

- Walking now has both **health value** and **utility value**.
- The feeling of *"producing your own power"* creates a sense of achievement.
- Sedentary individuals may feel motivated to walk more because every step has a measurable outcome.
- Gamified goals (like daily energy targets) can help build consistent exercise habits.

This dual-purpose approach—fitness + energy harvesting—creates a more engaging and meaningful user experience compared to standard fitness trackers.

3. Solid-State Reliability and Near Zero Maintenance

Most human-powered generators rely on mechanical systems such as gears, hand-cranks, or rotating dynamos. These components inevitably wear out due to friction, require lubrication, and eventually fail from mechanical fatigue. In contrast, piezoelectric harvesting is **solid-state**—meaning it has no moving parts.

Advantages of this solid-state architecture include:

- **No mechanical wear and tear**, ensuring a long lifespan.
- **High endurance**, with many ceramic PZT discs surviving more than 10810^8108 compression cycles.
- **No lubrication, alignment, or servicing required**.
- **Silent operation** with no vibration, noise, or heat generation.

Once encapsulated inside a shoe sole, the piezo array remains protected and continues functioning with minimal degradation, making it ideal for long-term deployments in harsh environments.

4. Data-Driven Energy Awareness and Smart Insights

Traditional portable chargers provide no visibility into how energy is produced or consumed. EcoPiezo PowerStore changes this by offering a complete data-driven monitoring experience. Users gain detailed insights into their personal movement-based energy generation.

The system allows users to monitor:

- **Live voltage produced per step**, showing how each foot impact converts to measurable electrical output.
- **Daily, weekly, and monthly energy graphs**, allowing users to identify long-term patterns and consistency in energy generation.
- **Charging and storage status**, including when the battery is trickle-charging or when power output increases during fast or heavy walking.
- **Total energy harvested over time**, helping users observe cumulative progress and how much power they've generated since first use.

- **Gait characteristics and step analytics**, revealing how speed, pressure, and foot placement influence voltage output.

This level of insight helps users understand:

- **How much electricity their daily movement truly produces** (turning steps into quantifiable energy).
- **How walking speed, stride length, and impact force influence voltage**, encouraging users to improve movement patterns for higher output.
- **How much power their low-energy devices consume**, helping them optimize device usage and battery life.

By visualizing this information on a smart IoT dashboard, users become more mindful of energy habits and develop an informed, sustainable approach to personal power consumption.

5. Self-Sufficiency and Independence from Power Grids

EcoPiezo PowerStore offers one of the most valuable advantages in modern wearable technology: the ability to produce electricity anytime, anywhere, without relying on traditional charging sources.

Key strengths include:

- **Independence from charging ports and wall sockets**, giving users personal energy freedom.
- **Functionality in remote or low-resource environments**, including forests, mountains, construction sites, villages, and disaster zones.
- **Full operation even without sunlight**, unlike solar chargers that fail indoors or during the night.
- **Unlimited power availability as long as the user walks**, making it a continuous renewable micro-power source.
- **Essential emergency energy**, allowing the user to generate enough charge to send an SOS signal or power a beacon simply by walking for a few minutes.

This makes EcoPiezo especially suitable for travelers, trekkers, remote workers, rescue teams, and communities that face frequent power outages or lack stable electricity infrastructure.

6. Seamless Integration with Wearables

EcoPiezo PowerStore is designed to blend naturally into everyday clothing, offering power generation without any extra effort from the user.

Wearable integration advantages include:

- **Fully embedded inside footwear**, making the system invisible, maintenance-free, and easy to use.
- **No behavioral changes required**, since walking is already a natural daily activity.

- **No need to carry additional devices**, wires, panels, or chargers.
- **Automatic power generation**, happening silently in the background each time the foot strikes the ground.
- **Total comfort and convenience**, making it suitable for children, elderly individuals, outdoor professionals, office workers, and athletes.

EcoPiezo works for:

- Children who need location safety trackers
- Elderly individuals requiring movement or fall monitoring
- Trekking and hiking enthusiasts needing emergency power
- Professionals who move frequently throughout the day

Unlike portable solar panels or power banks, EcoPiezo requires **zero setup**. There is nothing to unfold, attach, or activate—the user simply walks, and the system immediately begins generating energy

7.2 Practical Applications (with Real-Time Examples)

7.2.1. Defence and Tactical Operations

Modern soldiers depend on a wide array of electronics such as encrypted radios, GPS units, real-time communication systems, drone controllers, night-vision optics, target designator systems, and wearable biometric sensors. These devices consume substantial power, forcing soldiers to carry around **10–15 pounds of extra batteries** during extended missions. EcoPiezo-integrated combat boots can significantly reduce this battery burden.

EcoPiezo enables:

- Continuous **trickle-charging** while soldiers march or patrol.
- Powering low-energy tactical devices like beacon transmitters.
- Extending mission time by ensuring critical electronics stay alive.
- Reducing the number of spare batteries carried in field gear.
- Improving mobility and lowering fatigue from heavy loads.

Real-Time Example:

The U.S. Army's **Nett Warrior System** and the U.K.'s **Virtus Soldier System** are actively looking for self-powered wearables to reduce reliance on Lithium-Ion modules. EcoPiezo-based smart boots could integrate into these systems to give soldiers sustainable, movement-based charging

7.2.2. Smart Healthcare and Geriatric Support

Elderly individuals—especially those with dementia, Alzheimer's disease, Parkinson's disease, or balance disorders—require constant monitoring. However, many wearable trackers depend on daily charging, which patients often forget.

EcoPiezo footwear enables:

- Self-powered GPS or Bluetooth tracking for patient location safety.
- Continuous harvesting of energy from daily walking in homes or care centers.
- Always-on fall detection systems that never "run out of battery."
- Gait pattern monitoring for medical diagnosis and early disease detection.
- Automatic analysis of walking irregularities, such as Parkinson's **Freezing of Gait (FOG)**.

Real-Time Example:
Healthcare systems in Japan and South Korea use smart shoes to track elderly patients. EcoPiezo could eliminate charging issues, making such shoes fully self-sufficient.

7.2.3. Wilderness Survival and Outdoor Recreation

Hikers, trekkers, mountaineers, and campers frequently travel into areas where electricity is unavailable for days. Running out of battery can disable GPS navigation, emergency distress beacons, or digital compasses—often leading to life-threatening situations.

EcoPiezo footwear provides:

- A reliable, continuous supply of emergency micro-power.
- Enough charge generation to send SOS messages simply by walking.
- Backup power for low-draw devices like satellite messengers (e.g., Garmin inReach).
- High survival probability in emergencies with dead batteries.
- Better reliability than solar chargers, which fail in dense forests or at night.

Real-Time Example:
The **Indian Himalayan trekking community** frequently faces communication blackouts. An EcoPiezo-enabled survival shoe would allow trekkers to generate essential power while navigating remote trails.

7.2.4. Smart Cities and IoT Ecosystems

As urban environments continue to evolve into smart cities, wearable sensors and mobile IoT nodes are becoming part of the city's data fabric. EcoPiezo technology can power such wearables without adding strain to the city's energy grid.

EcoPiezo supports:

- Smart shoe networks that provide city-level mobility data.

- Energy-harvesting wearables for cyclists, runners, and daily commuters.
- Self-powered micro-IoT transmitters for environmental monitoring.
- Pedestrian density analytics for urban planning and crowd control.

Real-Time Example:

Cities like **Singapore, Dubai, and Amsterdam** use pedestrian movement data for traffic optimization. EcoPiezo-powered shoes could feed reliable real-time movement analytics without external charging needs.

7.2.5. Education, Research, and STEM Innovation

EcoPiezo PowerStore also serves as a powerful educational and research platform. Its combination of renewable energy, sensors, IoT, cloud analytics, and biomechanics makes it a multi-disciplinary teaching tool.

It can be used to teach:

- Renewable energy harvesting techniques.
- Mechatronics, embedded systems, and sensor interfacing.
- IoT architecture, cloud communication, and real-time databases.
- Human gait analysis and wearable system design.
- Power management and microelectronics.

Real-Time Example:

Universities such as **MIT, Stanford, IIT Bombay, and NUS** run wearable energy harvesting research labs. EcoPiezo prototypes can be used in similar classroom or lab projects to demonstrate energy autonomy.

7.2.6. Consumer Wearables and Lifestyle Gadgets

As consumer wearables continue to grow, powering them autonomously becomes increasingly important. EcoPiezo technology offers a sustainable alternative to frequent charging.

Future EcoPiezo-powered gadgets include:

- Smart shoes with integrated step counters.
- Bluetooth tracking tags for personal belongings.
- Fitness and wellness wearables with energy autonomy.
- GPS or BLE location trackers for kids and pets.
- Shoe-integrated lighting for visibility at night.
- Micro-IoT devices that operate without batteries.

Real-Time Example:

Companies like **Nike, Adidas, Xiaomi, and Decathlon** are developing smart shoes with sensors. Integrating EcoPiezo harvesting would eliminate frequent charging, making such wearables more practical and eco-friendlier.

CONCLUSION AND FUTURE SCOPE

Chapter VIII

CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

The EcoPiezo PowerStore project stands as a comprehensive demonstration of how everyday human motion can be transformed into a meaningful source of renewable energy. Through this work, we have shown that energy harvesting from footwear is not only technically feasible, but also highly practical, user-friendly, and capable of being integrated into a modern IoT ecosystem. Unlike traditional approaches that rely on fixed piezoelectric floor tiles or large mechanical structures, our solution shifts the focus to the individual—turning each step into a small but significant contribution toward autonomous power generation.

The successful implementation of **piezoelectric energy harvesting**, combined with **ESP32-based wireless communication** and **Firebase cloud storage**, has elevated the system far beyond a basic electronics experiment. What began as a simple concept of “generating power by walking” has evolved into a smart, data-driven wearable platform capable of monitoring energy output, tracking user movement, and engaging users through intuitive visual feedback. The mobile application developed using MIT App Inventor plays a crucial role in this transformation, creating a bridge between physical energy harvesting and digital user experience. It enables real-time monitoring of voltage, step count, and accumulated energy—all of which help users understand and appreciate the renewable power they generate through their daily motion.

The system also successfully meets the original design objectives, which included building a high-efficiency harvester, implementing a safe and stable storage system, enabling IoT connectivity, and creating an interactive user interface. Each subsystem—from the piezoelectric sensor array and rectification circuit to the cloud database and Android application—works cohesively to form a reliable, self-contained energy harvesting ecosystem. The project demonstrates how interdisciplinary integration—spanning electronics, renewable energy systems, embedded programming, biomechanics, and cloud computing—can lead to a functional prototype with real-world value.

Perhaps most importantly, the EcoPiezo PowerStore highlights the potential of human kinetic energy as a renewable resource. While each individual step generates only a small amount of power, the cumulative effect over thousands of steps per day becomes meaningful, especially when applied toward low-power IoT devices. The project successfully fosters environmental awareness, promotes physical activity, and introduces a futuristic vision where wearable technologies are self-powered and sustainably designed. Ultimately, the EcoPiezo PowerStore serves as a foundation for future innovations in wearable energy harvesting and intelligent personal electronics.

8.2 Future Scope

Although the prototype proves the core concept effectively, the potential for expanding, refining, and scaling EcoPiezo PowerStore is enormous. Several promising directions exist for future research and development, allowing this system to evolve from an academic prototype into a commercially viable and technologically advanced wearable platform.

1. Advanced Materials and Improved Durability

The current design uses ceramic piezoelectric discs, which are efficient but inherently brittle. Future versions of the system can benefit significantly from using **PVDF (Polyvinylidene Fluoride)** or other flexible polymer-based piezoelectric materials. PVDF is lightweight, bendable, shock-resistant, and can be shaped to match the contour of an insole. This not only improves durability and comfort but also allows the entire insole surface area to be used for energy harvesting, resulting in far greater power output. The transition from rigid ceramic discs to flexible polymer films represents a major step toward commercial-grade wearable harvesting technology.

2. Machine Learning and Predictive Analytics

The continuous flow of real-time data to Firebase contains highly valuable gait information. Voltage fluctuations, step rhythms, pressure distributions, and movement patterns combine to form a unique **gait signature** for each user. By applying machine learning algorithms to this dataset, the system can evolve into an intelligent health-monitoring platform capable of detecting gait abnormalities, early signs of orthopedic problems, rehabilitation progress, or neurological disorders such as Parkinson's disease. ML models can also enhance calorie estimation, fatigue detection, step classification, and even differentiate between activities such as walking, jogging, climbing, and running based on harvested energy patterns.

3. Hybrid Energy Harvesting Modes

Future iterations of EcoPiezo PowerStore can integrate multiple renewable energy sources to maximize output. For example, embedding **flexible solar strips or thin-film solar cells** on the upper portion of the shoe can capture sunlight during outdoor activities. Combining solar and piezoelectric harvesting creates a hybrid renewable shoe that generates power both while walking and while stationary. Additional possibilities include harvesting thermal energy from foot heat, integrating micro dynamos in high-stress zones, or embedding triboelectric nanogenerators (TENGs) for even greater output.

4. Power Optimization for More Devices

With advancements in low-power microcontrollers, Bluetooth beacons, smart shoe modules, and health sensors, the system can be optimized to support more wearable devices simultaneously. Future versions could power smart insoles, orthopedic pressure sensors, GPS modules, RFID trackers, emergency signalling devices, or Bluetooth LE beacons used in smart buildings and IoT networks. Through efficient power management circuits, even small amounts of energy could be used more intelligently by scheduling, prioritizing, and regulating energy consumption in real time.

5. Integration into Smart Cities and IoT Infrastructure

The data generated by thousands of EcoPiezo-equipped users can contribute to large-scale analytics for smart city planning. Pedestrian density maps, walking trends, crowd flow modeling, and real-time movement heatmaps can be derived from anonymous aggregated data. This information can support urban planning, transportation design, emergency management, and public health initiatives. The shoe-based system could also communicate with roadside IoT nodes, traffic signals, or public information networks.

6. Commercialization and Industrial Design Improvements

To bring EcoPiezo PowerStore into mainstream use, future work must focus on industrial design elements such as waterproofing, shock absorption, ergonomic placement of sensors, flexible circuit integration, and embedding electronics in ultra-thin layers. Manufacturers can develop fully integrated smart-insoles with energy harvesting, cloud connectivity, and built-in sensors—all contained in a sleek, lightweight form factor suitable for everyday use. Commercial partnerships with sports brands, healthcare device manufacturers, and IoT companies could lead to large-scale production.

7. Self-Sustaining Emergency Systems

With improved energy storage and optimized electronics, EcoPiezo PowerStore could evolve into a reliable emergency communication device. In disaster zones where electricity infrastructures are destroyed, even a few minutes of walking could produce enough power to send a distress signal or activate a location beacon. This can be extremely valuable for hikers, rescue teams, military personnel, and people in geographically challenging areas.

8. Environmental Impact and Large-Scale Deployment

Future research can also examine the environmental benefits of widespread adoption. If millions of people use piezoelectric shoes daily, the cumulative reduction in dependency on grid electricity for personal devices could be substantial. Analyses on lifecycle sustainability, recyclability, and reduced e-waste can provide insights into how large-scale deployment of wearable energy harvesting positively contributes to environmental sustainability.

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REFERENCES

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APPENDIX

APPENDIX

Arduino® UNO R3 Datasheet

1. Board Overview & Core Specs

The UNO R3 is a microcontroller board based on the **ATmega328P**. It is celebrated for its ease of use and extensive documentation, serving as a standard entry point for beginners while remaining robust enough for industrial and educational applications.

- **Processor:** ATmega328P (running up to 20 MHz)
- **USB Bridge:** ATmega16U2 (handles USB-to-Serial communication)
- **Input Voltage (VIN):** 6V – 20V
- **Operating Temperature:** -40°C to 85°C
    - *Note: Extreme temperatures may affect voltage regulators and oscillators.*

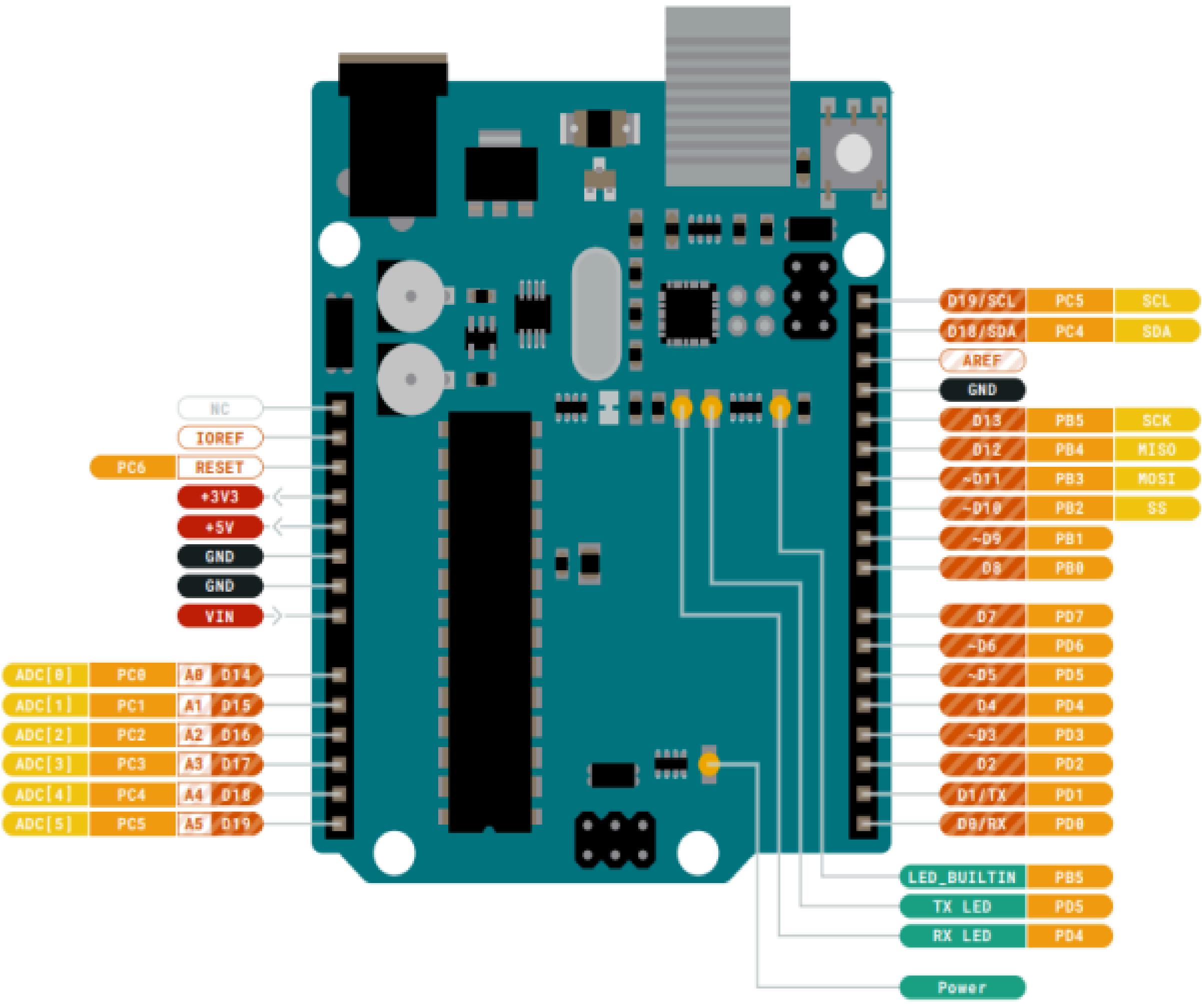


Fig:9.1 Arduino Uno R3 Pinout

2. Connectivity & Pinout

The board features a comprehensive set of headers for connecting sensors, actuators, and shields.

Power & Analog (JANALOG Header)

Pin	Function	Description
IOREF	Reference	Voltage reference for digital logic (connected to 5V).
Power	3.3V / 5V	Regulated power rails.
GND	Ground	Common ground connection.
VIN	Input	Voltage input for external power sources (6-20V).
A0-A5	Analog/GPIO	6 Analog inputs (10-bit resolution). **A4/A5** double as I2C (SDA/SCL).

Digital I/O (JDIGITAL Header)

Pin	Function	Description
D0-D1	UART	Serial communication (RX/TX).
D2-D13	Digital/GPIO	General purpose digital I/O.
SPI	D10-D13	Pins D10 (SS), D11 (MOSI), D12 (MISO), D13 (SCK) handle SPI communication.
AREF	Reference	Analog reference voltage for the ADC.

3. Key Components

The board topology includes several critical components for operation and safety:

- **Regulator (U1):** SPX1117M3-L-5 (5V regulator).
- **Oscillator (Y1):** ECS-160-20-4X-DU (Ensures precise timing).
- **Protection:** The board includes a resettable polyfuse to protect your computer's USB ports from shorts and overcurrent.

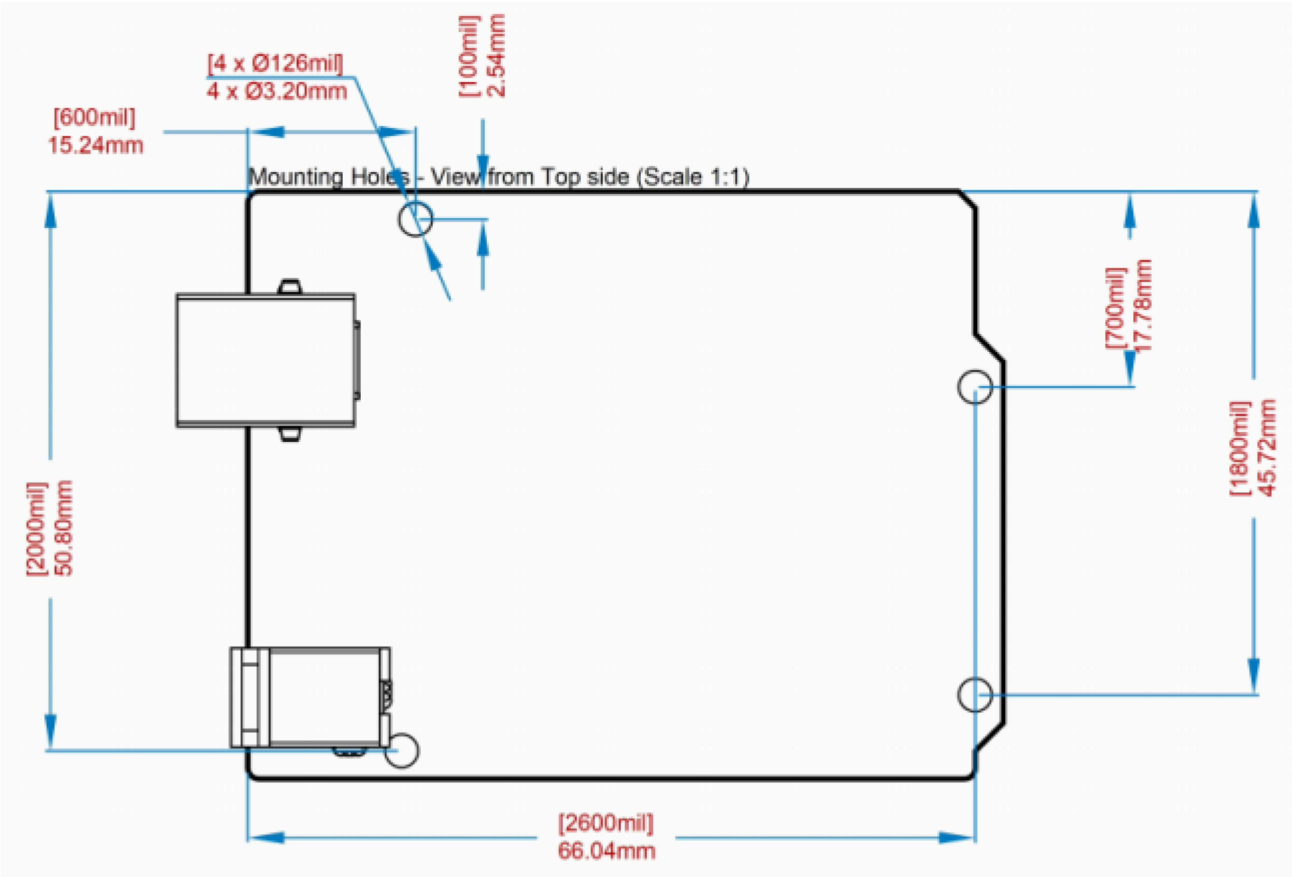
4. Getting Started

The datasheet emphasizes two main ways to program the board:

1. **Arduino IDE (Desktop):** For offline programming. Requires a USB-B cable which also provides power to the board.
2. **Arduino Cloud Editor:** An online platform that allows you to code in the browser. It keeps all board definitions up-to-date automatically and requires a simple plugin installation.

5. Compliance & Safety

- **Certifications:** CE, RoHS, REACH, and FCC compliant.
- **Conflict Minerals:** Arduino declares their products contain conflict minerals (Tin, Gold, etc.) only from conflict-free sources.
- **Radio Frequency:** The device complies with FCC Part 15 and should be operated with a minimum distance of **20cm** from the body.



Board outline

Fig:9.2 Arduino Uno R3 Board outline

ESP32 DevKit V1 Datasheet Overview

Based on standard specifications, this document outlines the core specifications, connectivity, and details for the **ESP32 DevKit V1** (commonly the DOIT version), a powerful Wi-Fi and Bluetooth-enabled microcontroller board.

1. Board Overview & Core Specs

The ESP32 DevKit V1 is a low-cost, low-power system on a chip (SoC) microcontroller with integrated Wi-Fi and dual-mode Bluetooth. It is vastly more powerful than standard 8-bit microcontrollers, making it ideal for IoT projects.

- **Processor:** Xtensa® Dual-Core 32-bit LX6 microprocessor.
- **Clock Speed:** Adjustable between 80 MHz and **240 MHz**.
- **Memory:** 520 KB Internal SRAM, 448 KB ROM.
- **Storage:** typically 4MB SPI Flash (external to the chip, on the module).
- **Wireless:**
  - Wi-Fi: 802.11 b/g/n (up to 150 Mbps).
  - Bluetooth: v4.2 BR/EDR and Bluetooth Low Energy (BLE).
- **Input Voltage (VIN):** 5V – 12V DC.
- **Logic Voltage: 3.3V** (Note: GPIO pins are *not* 5V tolerant).

2. Connectivity & Pinout

The board exposes most of the ESP32 pins to headers. Note that the specific pin layout can vary slightly between manufacturers (30-pin vs. 36-pin versions), but the functionality remains consistent.

Power Pins

Pin	Description
VIN	Input voltage (5V - 12V). Connect USB or external battery here.
3V3	3.3V Output from the on-board regulator. Do not power the board via this pin if VIN is connected.
GND	Common ground connection.

GPIO & Peripherals

The ESP32 features multiplexed I/O, meaning many pins can perform multiple functions (PWM, SPI, etc.) defined in software.

Function	Description	Key Pins (Default)

ADC	Analog-to-Digital Converter (12-bit).	**ADC1:** GPIO 32-39 **ADC2:** GPIO 0, 2, 4, 12-15, 25-27 *(Cannot use ADC2 while Wi-Fi is active)*
DAC	Digital-to-Analog Converter (8-bit).	**DAC1:** GPIO 25 **DAC2:** GPIO 26
Touch	Capacitive Touch Sensors.	GPIO 4, 15, 13, 12, 14, 27, 33, 32, etc.
I2C	Inter-Integrated Circuit.	**SDA:** GPIO 21 **SCL:** GPIO 22
SPI	Serial Peripheral Interface.	**VSPI:** GPIO 23 (MOSI), 19 (MISO), 18 (CLK), 5 (CS) **HSPI:** GPIO 13 (MOSI), 12 (MISO), 14 (CLK), 15 (CS)
UART	Serial Communication.	**UART0:** TX (GPIO 1), RX (GPIO 3) *(Used for USB flashing)* **UART2:** TX (GPIO 17), RX (GPIO 16)
PWM	Pulse Width Modulation.	All output GPIOs support software PWM.

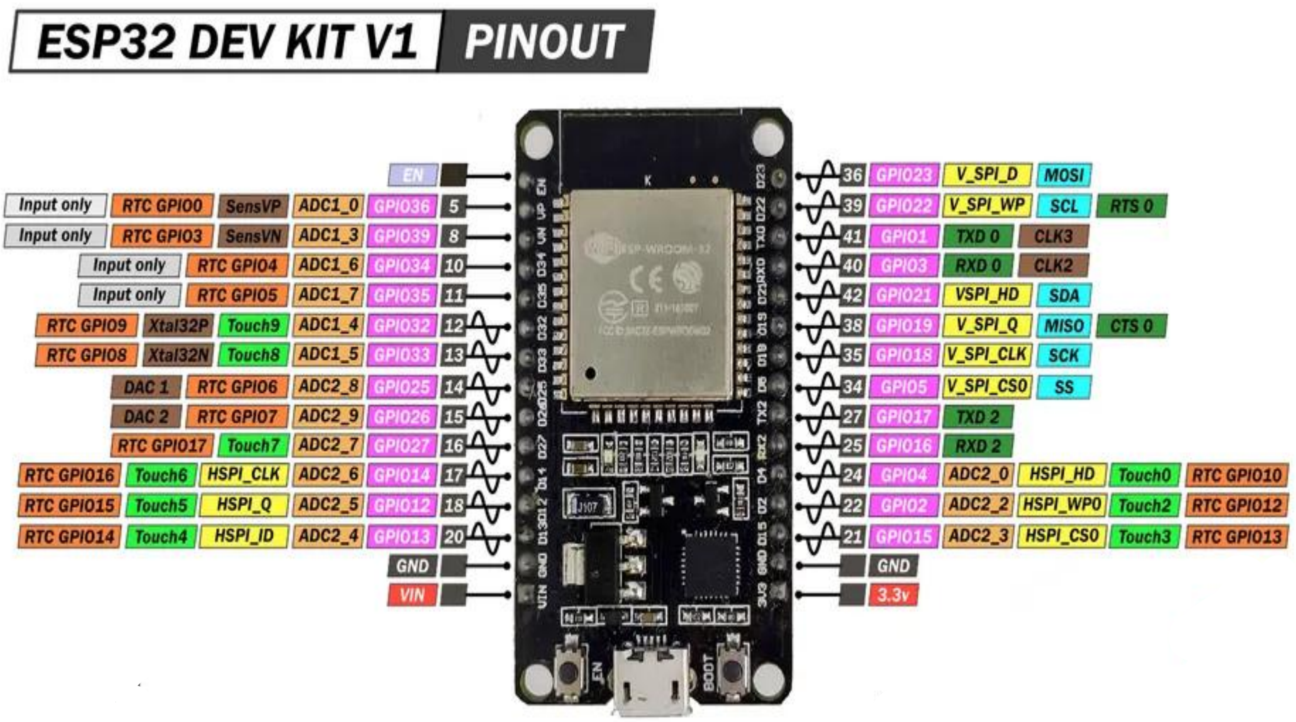


Fig:9.3 ESP32 pinout

3. Key Components

- **ESP-WROOM-32 Module:** The metal-shielded can containing the ESP32 chip and antenna.
- **USB-to-UART Bridge:** typically **CP2102** or **CH340** chip. Requires specific drivers on the computer.
- **Voltage Regulator:** AMS1117-3.3 (Drops VIN 5V to 3.3V for the chip).
- **Buttons:**
  - **EN:** Reset button.
  - **BOOT:** Download button. Used to put the board in flashing mode (sometimes required to hold down while uploading).

4. Getting Started

To program the ESP32 DevKit V1:

1. **Install Drivers:** Ensure the driver for the CP210x or CH340 USB bridge is installed on your OS.
2. **Arduino IDE Setup:**
   - Go to **File > Preferences**.
   - Add this URL to "Additional Board Manager URLs": https://raw.githubusercontent.com/espressif/arduino-esp32/gh-pages/package_esp32_index.json
   - Go to **Tools > Board > Boards Manager**, search for "esp32", and install "esp32 by Espressif Systems".
3. **Select Board:** Choose **"DOIT ESP32 DEVKIT V1"** in the boards menu.

5. Important Warnings

- **3.3V Logic Level:** Unlike the Arduino UNO, the ESP32 operates at 3.3V. Connecting 5V logic signals (from 5V sensors or an Arduino UNO) directly to ESP32 pins can damage the chip. Use a logic level converter.
- **Current Draw:** The ESP32 can draw significantly more current (peaks >500mA) than an Arduino during Wi-Fi transmission. Ensure your power supply is adequate.

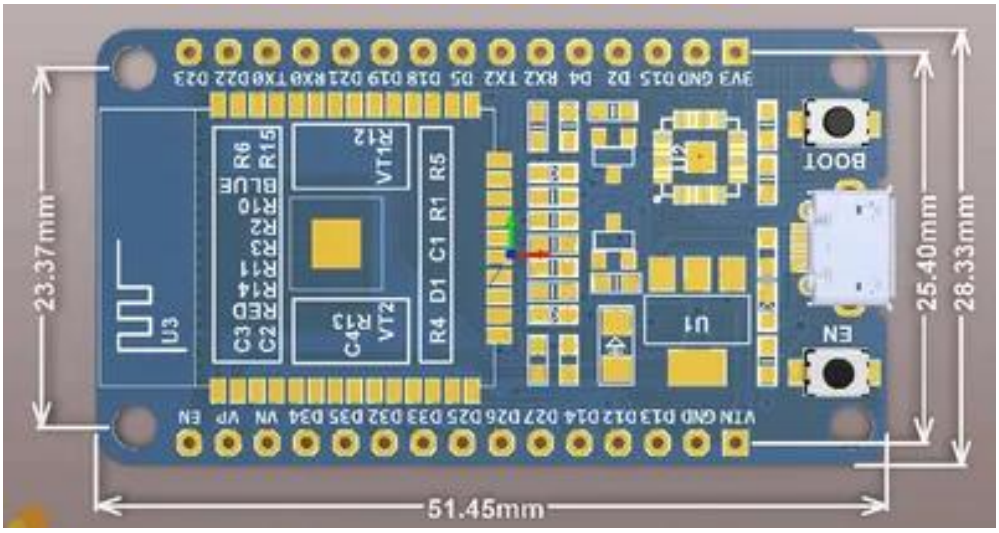


Fig:9.2 ESP32 DEVKIT V1 Board outline

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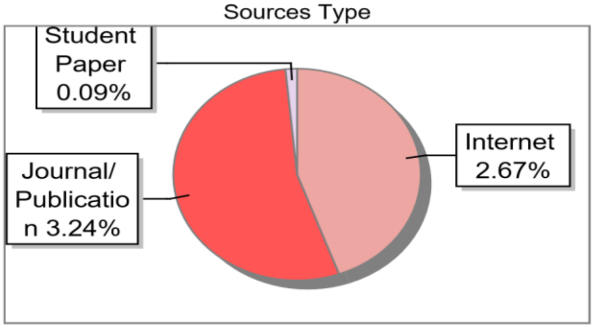

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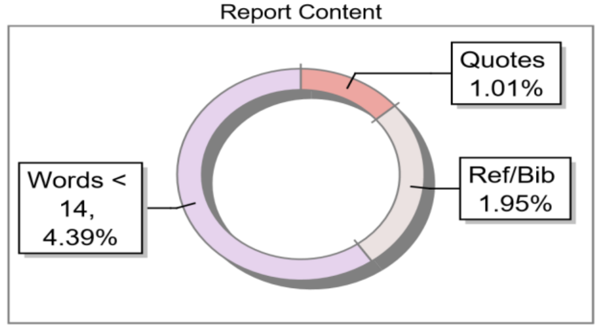

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