



Palestine Polytechnic University

College of Information Technology and Computer Engineering

Title of the project:

IOT based Advanced and Secure Footstep power generator

Names of the students:

Sana Albaw

Sara Allan

Shadan Darabee

Supervisor:

Dr. Amal Al-Dweik

Acknowledgment

In the name of "Allah", the most beneficent and merciful who gave us strength, knowledge and helped us to get through this project.

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Abstract

Global energy demand has increased, and traditional power producing techniques have a negative impact on the environment. Therefore, we are here to provide an unconventional method of power generation that continuously utilizes lost energy in order to meet the expanding need for energy.

The fundamental idea behind this system is to capture energy created when someone walks on a particular plate and transform it into electrical energy. The generated energy is then stored in a rechargeable battery to be used later. The amount of power produced using this unconventional method depends on how many steps a person walks and her/his weight. The system uses IoT technology by connecting it to a cloud that stores and analyzes the obtained data from the system. Additionally, the system enables us to view the output voltage amount, weight of steppers and number of steps using LCD. The system is secured; it allows only authorized users to use the generated power that is stored in the rechargeable battery.

The implemented system is tested and it is successfully achieves all its objectives. The system was able to generate 28 volts as a maximum voltage that can be obtained from one step.

الملخص

لقد زاد الطلب العالمي على الطاقة ، وللتقنيات التقليدية لإنتاج الطاقة تأثير سلبي على البيئة. لذلك ، نحن هنا لتقديم طريقة غير تقليدية لتوليد الطاقة تستخدم باستمرار الطاقة المفقودة من أجل تلبية الحاجة المتزايدة للطاقة.

الفكرة الأساسية وراء هذا النظام هي التقاط الطاقة المتولدة عندما يمشي شخص ما على صفيحة معينة وتحويلها إلى طاقة كهربائية. ثم يتم تخزين الطاقة المتولدة في بطارية قابلة لإعادة الشحن لاستخدامها لاحقًا. تعتمد كمية الطاقة المنتجة باستخدام هذه الطريقة غير التقليدية على عدد الخطوات التي يمشيها الشخص ووزنه. يستخدم النظام تقنية إنترنت الأشياء من خلال توصيلها بسحابة تقوم بتخزين وتحليل البيانات التي تم الحصول عليها من النظام. بالإضافة إلى ذلك ، يتيح لنا النظام عرض مقدار جهد الخرج ووزن السائر وعدد الخطوات باستخدام شاشة LCD النظام آمن. يسمح فقط للمستخدمين المصرح لهم باستخدام الطاقة المولدة المخزنة في البطارية القابلة لإعادة الشحن.

يتم اختبار النظام المنفذ وتشغيله بنجاح ويحقق جميع أهدافه. كان النظام قادرًا على توليد 28 فولت وهذا هو أقصى جهد يمكن الحصول عليه.

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Chapter one

Introduction

1.1 Preface

Finding sustainable and renewable energy sources is one of the most significant difficulties that humanity faces. Thus, our initiative aims to look into that. As people are walking daily, this movement can be used to generate power. We will use this movement to our advantage by turning the mechanical energy generated by footsteps into electrical energy, which we can store in rechargeable batteries to be used later.

1.2 Project Aims and Objectives

Our aim is to leverage human movements to generate sustainable energy that will be stored in a battery, the system is connected to the cloud to collect and analyze data and provides secure use of the generated power.

It is necessary to accomplish the following aims in order to realize this worthwhile aims:

- ✓ The system aims to generate power from moving steps. This is accomplished by building a plate that transfers the mechanical power to electrical power saved in a rechargeable battery.
- ✓ The system aims to preserve security by using a technology that permits only authorized people to use the system.
- ✓ The system aims to analyze the collected data observed by the system and helps users to find the available plate locations, the amount of preserved power in each plate and the peak and off hours, by using the IoT technology.

1.3 Problem Statement

Energy is essential for life. However, as population and other aspects of society develop, there is an enormous demand for energy. The best way to obtain energy is to produce it from a source that is limitless or unrestricted, such as human movement; because it is a waste of power that we should exploit. Walking is a daily habit which human do that does not require extra effort to generate power and is a promising clean alternative to electrical power especially in highly

populated countries. Such project should be designed to protect the generated power from abuses. Therefore, security issues should be added. There is a need for multiple plates to generate power in different locations, where the use of IoT will help in collecting and analyzing data that is collected from the different plates to get best decision regarding the best hours of using the system.

1.4 Project Requirements

1.4.1 Functional Requirements

The system should be able to:

- Be user friendly: the LCD gives the users information and instructions of how to use the system.
- Collect data: number of steps, weight of the steppers and the time holding the steps are all should be collected by the system and sent to cloud to be used later.
- Analyze collected data to decide the peak and off hours of the system.
- Give decisions to prevent unauthorized users from using the power.

1.4.2 Non Functional Requirements

- Secure: only authorized users can use the system. The abuse of the system is not allowed, too.
- Usable: users can get voltage by using USB cable.
- Effective: it will help customers charge suitable/permitted devices in an efficient manner.
- Recoverability: all system data are uploaded on cloud.
- Maintainability: easy to fix.
- Availability: steps on the plate can generate power at any time.

- Scalability: the performance is unaffected by the addition of more plates. On the contrary, the system will be more efficient.
- Integrity: the system's data cannot be altered accidentally.

1.4.3 Security Requirements

Our system will be adopted from specific organization and only the people who the company is concerned with can allow them to use the system and this is achieved by owning specific card by them so they can use the generated power by the system.

1.5 System Description

The major goal is to construct a secure, noise-free power generator that is activated by human foot pressure on sensors that are positioned beneath the platform as shown in figure 1.1. Electrical energy is created by converting the mechanical power to an electrical power. The energy is kept in a rechargeable battery to be used later. By using secure mechanism, the system can only be used by authorized users. By using the IoT technology the system is connected to the cloud. Therefore, the system will be more efficient in analyzing and helping users to choose the system efficiently.

The cloud will keep an eye on the system and perform data analysis to determine when it is optimal to charge, generate more power, when, and who is charging.

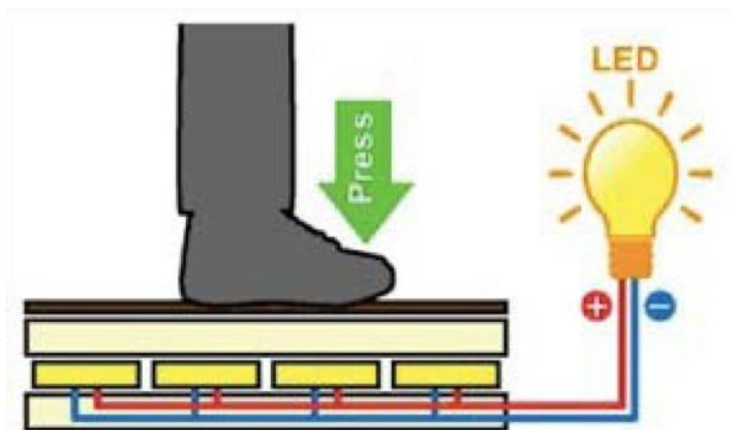


Figure 1.1: Illustrative view of the system

1.6 Project Limitations/Constraints

- The system should be connected to internet permanently.
- The weight of the steppers should not exceed the limit (75 kg).
- The system will be designed using three plates, however only one plate will be implemented in reality.

1.7 Project Schedule

There are six tasks to accomplish the project, as shown in table 1.1.

Task 1: finding the idea

Task 2: defining and analyzing the system requirements

Task 3: software and hardware system design

Task 4: implementation

Task 5: testing and result analysis

Task 6: documentation

Table 1.1 Gantt chart of project tasks during the two semesters

Task	Duration (weeks)															
	First Semester								Second Semester							
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
T1	█	█														
T2			█	█	█	█										
T3					█	█	█	█	█							
T4									█	█	█	█	█	█		
T5														█	█	█
T6	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█

1.8 Project Outline

The structure of this report is as follows: The introduction and project overview are presented in chapter 1. Chapter 2 discusses the theoretical background of the project, and literature review. Chapter 3 discusses the system's conceptual design, system components and different design options, pseudocode of the system, design diagrams, and schematics of the system design. Chapter 4 includes the hardware and software implementation of the system, chapter 5 shows the testing and system analysis and finally chapter 6 is about the conclusion.

Chapter two

Theoretical Background

2.1 Preface

In this chapter we will review the important theoretical concept that will be used within the project and present the previous works and techniques that others used in similar projects.

2.2 Theoretical Concepts

Our project focused on generating power from steps of human movements by converting the mechanical energy to electrical energy. It aims to design integrated system that achieves and preserves the power to use it later. The human race depended on huge amounts of electric power to fuel our evolution, but they are also non-renewable and rapidly depleting, so we need renewable energy that are replenished constantly such as solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen [1]. In our project, the power will be generated from human walking.

The most well-known renewable energy sources are:

- **Solar power**

More than 486GW of installed capacity makes solar the third biggest renewable power source in the world, with photovoltaic (PV) technology being dominant. The use of concentrating solar power (CSP) technology is also on the rise, with global CSP installed capacity reaching 5.5GW by the end of 2018. China, US, Germany, Japan, Italy, and India possess the biggest solar PV capacity in the world, while Spain has 42% of the global CSP capacity [21].

- **Wind energy**

Wind is the second most widely used renewable energy source, as global installed wind power capacity exceeded 563GW in 2018, accounting for approximately 24% of the world's total renewable energy generation capacity [21].

- **Bio-power**

Bio-power is the fourth biggest renewable power source after hydro, wind and solar. The world's net electricity production capacity from bio-mass currently exceeds 117GW, while global bio-power generation increased from 317TWh in 2010 to more than 495TWh in 2018 [21].

The system will generate the power using piezoelectric characteristics. It also uses the IoT technology and the system will be secured. The following subsections will present these important concepts briefly:

2.2.1 Piezoelectric Characteristics

Piezoelectric pressure sensors exploit the effect of converting mechanical energy into electrical power by measuring the voltage across a piezoelectric element generated by the applied pressure. They are very robust and are used in a wide range of industrial applications [4]. In our project, the piezoelectric sensor will be placed beneath the platform so when human foot force applied on it, the mechanical energy of this force will be turned into electrical energy, where the produced voltage is proportional to the generated pressure as shown in figure 2.1.

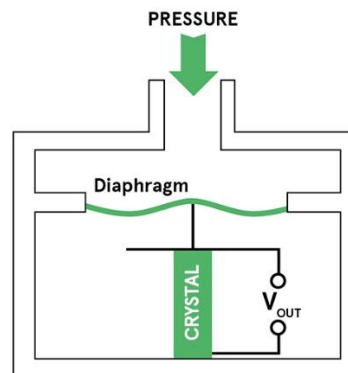


Figure 2.1: piezoelectric sensor working principle

The piezoelectric produces a voltage following equation 2.1.

$$V = \frac{dFt}{\epsilon_r \epsilon_0 A}$$

Equation 2.1: how piezoelectric produces voltage

Where:

V → voltage

d → piezoelectric coefficient

t → thickness

F → force

ϵ_r → relative permittivity

ϵ_0 → Vacuum permittivity

A → area

2.2.2 Internet of Things (IoT)

The term "Internet of things" refers to the physical items equipped with sensors, processing power, software, and other technologies that link to other systems and devices over the Internet or other communications networks and exchange data with them [2]. In our project, we will use this technology to connect the system with cloud to save data, monitor the system, make a statistical analysis for the users and decide the best time to charge and the best time to generate power. Other statistics regarding the number of steps, the weight of the steppers and the time holding the steps will be applied to. Here are some of IoT protocols that are used:

- **User Datagram Protocol (UDP)**

A communications protocol that enables process-to-process communication and runs on top of IP. UDP improves data transfer rates over TCP and best suits applications that require lossless data transmissions [3].

- **Advanced Message Queuing Protocol (AMQP)**

A software layer that creates interoperability between messaging middleware. It helps a range of systems and applications work together, creating standardized messaging on an industrial scale [3].

- **Message Queue Telemetry Transport (MQTT)**

A messaging protocol designed for lightweight machine-to-machine communication and primarily used for low-bandwidth connections to remote locations. MQTT uses a publisher-subscriber pattern and is ideal for small devices that require efficient bandwidth and battery use [3].

2.2.3 Security [5]

Security should be maintained to protect devices and services from being disrupted, stolen or exploited by unauthorized users. Security consists of two areas:

- **Physical security:**

Physical security is the protection of people, hardware, software, network information and data from physical actions, intrusions and other events that could damage an organization and its assets [5].

- **Information security**

Information security is also referred to as infosec. It includes strategies used to manage the processes, tools and policies that protect both digital and non-digital

assets. When implemented effectively, infosec can maximize an organization's ability to prevent, detect and respond to threats [5].

In our project, physical security was used to control access to the charging system of a specific entity which only its subscriber are allowed to use the system. To achieved that, RFID was used and each subscriber has his/her own cards. The system has no sensitive data of subscriber that may affect on them badly so it does not need encryption to data.

2.3 Literature Review

In this section, we will talk about some projects and ideas related to our project idea.

2.3.1 Walk to generate power [6]

This project was done by Amal Badarin and Wala' Zayed [6]. The system is designed based on the foot force applied on the “piezoelectric” sensors which are placed below the platform. Then the applied energy allows user to monitor the voltage. The voltage is stored in a Lead Acid battery. The circuit is connected to USB cable for charging some specific devices. All of these components convert voltage to power that enables the charging of devices like: Mobile, Tablets, MP3 devices, and charger light [6]. This project differs from our project that it does not use IoT technology and it is not secure.

2.3.2 Footstep Piezo Generator [7]

This project was done by Khalid Al-Hamoudi and et al [7]. The main idea is designing a system that generates voltage by the humane footsteps force. The system uses piezoelectric sensors that will convert the measurements of acceleration, force and pressure into electrical signals. The project had two subsystems. The weighting machine and the monitoring circuit. At first by placing the piezoelectric sensors under the weighting machine, the applied pressure on the weighting machine is converted into voltage (mechanical to electrical) that is provided to the microcontroller. The monitoring circuit is based on a microcontroller that allows the system to calculate the voltage charge and display it on the LCD display [7]. This project differs from our project that it does not use IoT technology and it is not secure.

2.3.3 Footstep Power Generation System [8]

The system generates voltage using footstep force. The system is placed at entry points where people travel through entrance or exits and they have to step on this device to get through [8]. These devices then generates a voltage on every footstep and when mounted in series they produces a sizeable amount of electricity. For this purpose, they used the piezoelectric sensors. A voltmeter is attached to the system in order to measure its output and small led

lights for demonstration [8]. This project differs from our project that it does not use IoT technology, it is not secure and doesn't display the generated voltage to users.

As shown in table 2.1, we will establish a system that will generate enough power to charge a mobile and to operate simple devices. The use of the IoT technology by connecting the system to the cloud is the essential difference between our project and previous projects. The voltage and number of steps will be displayed on LCD and this is another difference between our project and the second and the third ones. Moreover, the system will be secure that will allow only authorized users to use the power generator system and block authorized users who is abusing the system and this is not available in all previous projects.

Table 2.1: Summary of previous work

	(1) Walk to generate power	(2) Footstep Piezo Generator	(3) Footstep Power Generation System	(4, our project) IOT based Advanced and Secure Footstep power generator
Goals	Design and develop a free noise power generator to charge simple devices such as a mobile phone.	Design and develop a free noise power to be able to charge a mobile phone and a 12V lead acid battery.	Designed to be useful at public places like railway stations where a lot of people keep walking through all day.	Design and develop a secure, noise-free power generator using IoT technology.
Achievements	Generate enough power to charge mobile, also display voltage on LCD. The maximum amount of voltage that they generated was 76 volts.	Generate a few power but couldn't enough charge mobile also display number of steps and voltage generated.	Generate power to make a LED light.	In progress, but supposed to generate secure power that will be enough to at least charge a mobile phone.
Design components	Piezoelectric sensors, UNO(ATmega 328), LCD1 6*2, PCB, Battery, Platform, 12v adaptor, Resistors, Capacitors, Transistors(7805), IC Base, Diodes, LCD strips, LED strip, USB cable, USB Connector, LEDS, Push button, Soldering wire.	Various capacitors, Ultra-capacitors, Various resistors, Arduino UNO, Voltage regulator, Transistor BC547, 1N4007 diode, 12V Battery lead acid, LCD screen, Piezoelectric material, Weighing machine, Power transistors	Piezoelectric Crystal Material, Resistors Capacitors, Transistors, Cables and Connectors Diodes, PCB and Breadboards, LED Transformer/Adapter Push Buttons, Switch IC, IC Sockets Mounting Frame	Piezoelectric sensors, ESP32, LCD, Battery, Resistors, USB cable, Soldering wire, RFID card, load cells. [to be explained later in the next chapter]
Use of IoT technology	No	No	No	Yes
View data on LCD	Yes	Yes	No	Yes
Security	No	No	No	Yes
Maximum power/voltage generated	76 V	N/A	N/A	28 V

2.4 Summary

In this chapter we reviewed the main theoretical concepts, and showed how each of these concepts related to our project. Some of previously accomplished projects were discussed and the main differences to our project are raised, too.

Chapter three

System Design

3.1 Preface

In this chapter we will review the fundamental software and hardware components that will be used in our project. The different alternatives for each component. The conceptual description of the system and the general block diagram is presented. Also, we will review algorithms and methodologies of our system by using flowcharts, sequence diagram and use cases. The interactions and interfaces between components in schematic diagrams are shown, too.

3.2 System Components and Design Alternatives

This part describes the hardware and software components and their design alternatives.

3.2.1 Hardware Components

We have to use a control circuit to deal with the data received from the connected sensors, send the data to cloud using IoT technology, then make the proper decisions.

The control circuit, could be implemented using software application that run on a desktop. It could be a digital or an electronic circuit. Finally, a microcontroller-based system is another alternatives. In our system, the last choice (microcontroller-based system) is chosen as prescribed in the ILOS of the graduation project course.

3.2.1.1 Controller

As mentioned above, we need a microcontroller to control and manage the system. The options for the microcontroller will be used as listed in Table 3.1.

Table 3.1 List of Microcontroller alternatives

Microcontroller				
Types	Cost	Wi-Fi module	Number of pins	Memory module
Arduino mega [9]	Low cost	Does not built	1. 54 digital input/outputs 2. 16 analog inputs	Contains 268KB

Raspberry pi [10]	High cost	From Raspberry pi 3 model B and later built in Wi-Fi, older model not built in Wi-Fi	40 pins	No internal storage
ESP32[11]	Low cost	Built in Wi-Fi	18 x 12 bits ADC input channels	Contains 520KB of RAM

We choose ESP32 because it is suitable for achieving our system objectives, easy to operate, a low cost and with built-in Wi-Fi [11].

3.2.1.2 Power generation circuit

We need a circuit to convert the mechanical power of footstep to the corresponding electrical power. Piezoelectric sensor can be used to convert the mechanical energy to electrical power. Some of piezoelectric sensors are listed in table 3.2.

Table 3.2 Piezoelectric sensor alternatives [12]

Piezoelectric Sensor		
Types	Power consumption	Usage
Piezoelectric pressure sensor	Low power consumption	Measuring change in liquid and gas pressure

Piezoelectric force sensors	Low power consumption	Designed for generating analog voltage signals when a force is applied on
Piezoelectric accelerometers	Low power consumption	OEM applications

We choose piezoelectric force sensor because it meets the purpose of our project [12].

3.2.1.3 LCD

We need LCD to display the amount of voltage that will be stored in battery, the number of steps, and other guidelines. The options for the LCD are listed in Table 3.3.

Table 3.3 List of LCDs alternatives [13]

LCD		
Types	Size	Number of characters
16x2 character LCD display	2.96x5.56mm	32 characters
20x4 character LCD display	4.84x9.22 mm	80 characters
8x2 character LCD display	2.45x4.954 mm	16 characters

We choose 20*4 character LCD display because it can displays 20 characters per line and there is 4 lines so it is enough to display all information needed [13]. It needs small space, too.

3.2.1.4 USB Cable

The shape of the cable relies on the associated loads, such as: mobile and lighting, since it is used to charge the load that may be attached. List of alternatives are shown in table 3.4.

Table 3.4 USB cable alternatives [14]

USB Cable	
Types	Suitable for entrance of controller
USB Micro B	Yes
USB A	No
USB B	No

We choose USB Micro B because it is included in the chosen microcontroller.

3.2.1.5 RFID

We need RFID to make the system secure so only authorized user can use the system. The options for the RFID will be used are listed in Table 3.5.

Table 3.5 List of RFIDs alternatives [15]




RFID Cards				
Types	Cost	Battery	Reading distance	Size
Active RFID	High cost	Built in battery	200 m	Larger
Passive RFID	Low cost	Not built in battery	10 cm – 15 m	Smaller

We choose passive RFID because it is not built in battery that makes it very low cost and smaller in size [15].

3.2.1.6 Load Cells

We need load cell to measure the steppers' weight. The options for the Load cells are listed in Table 3.6.

Table 3.6 List of Load cells alternatives [16]

Load Cells			
Types	Size	Weight	Shape
Alloy steel flat thin force sensor load cell	34*34*2.5mm	50 Kg	
Single point load cell	130*30*22mm	3 – 120 Kg	
Micro load cell	130*31.8*31.8mm	1 – 25 Kg	

We choose alloy steel flat thin force sensor load cell because it meets the shape of plate in our project [16].

3.2.1.7 Rechargeable Battery

The system main aim is to store power in a rechargeable battery, so, it is necessary to add this component to the system. The options for the batteries are listed in Table 3.7.

Table 3.7 List of batteries alternatives [17]

Batteries		
Types	Range of voltage	Cost
Lead acid battery	4 – 6 V	High cost
Nickel-metal hydride	1.2 V	High cost
Lithium ion	3.7 V	Low cost

We choose lithium ion battery because it is lower cost, easy handling and long service life.

3.2.2 Software Components

The cloud system is needed to keep an eye on the system and perform data analysis to determine when it is optimal to charge, generate more power, and when and who is charging. The options for the used cloud are listed in Table 3.8.

Table 3.8 List of clouds alternatives

Clouds					
Types	Subscription	Storage space	Notifications	Triggering services	Data analytics
Google cloud [19]	Not free	15 GB free	Available	Available	Applicable
Amazon cloud [18]	Not free	5 GB free	Available	Available	Applicable
Cayenne [20]	Free	Free high storage space	Available	Available	Applicable

We choose cayenne because it is free, it has high storage space and it has a triggering service to send the microcontroller the needed notifications when needed.

3.3 Conceptual System Description

Our system will be designed to generate power through human footsteps as a source of renewable energy. The system is powered by ESP32 microcontroller and will use IoT technology by connecting it to the cayenne cloud as shown in the general block diagram of the system in figure 3.1. When the system is activated by allowing people to walk over a piezoelectric sensor it undergone some of pressure and this kinetic energy is converted into electrical energy. The produced energy is stored in a battery for a long time and can be used, later, by multiple users. The amount of obtained voltage is sent to the ESP32 to display it on the LCD. To use this power, the user should have a permission by using RFID card. When he/she swipes the card, the RFID reader scans RFID tags: If the information stored in the tag matches that on the system's database, the user is authorized. Therefore, the system turns on the charging service and he/she will be able to charge the device. If the information doesn't match, then the user he/she is an unauthorized. The system displays a message on the LCD indicating that he/she is unauthorized user. The collected data from plate, such as: the time of holding the steps, weight of steppers, and the number of steps, and the amount of generated power will be sent to the cloud via Wi-Fi using MQTT protocol. The cloud will analyze data to decide the peak and off times of the system according to the amount of generated voltage. The system consists of 3 plates, distributed in three crowded points. The design will consider these 3 plates as shown in figure 3.2. However, the real implementation will be only for one plate at this stage.

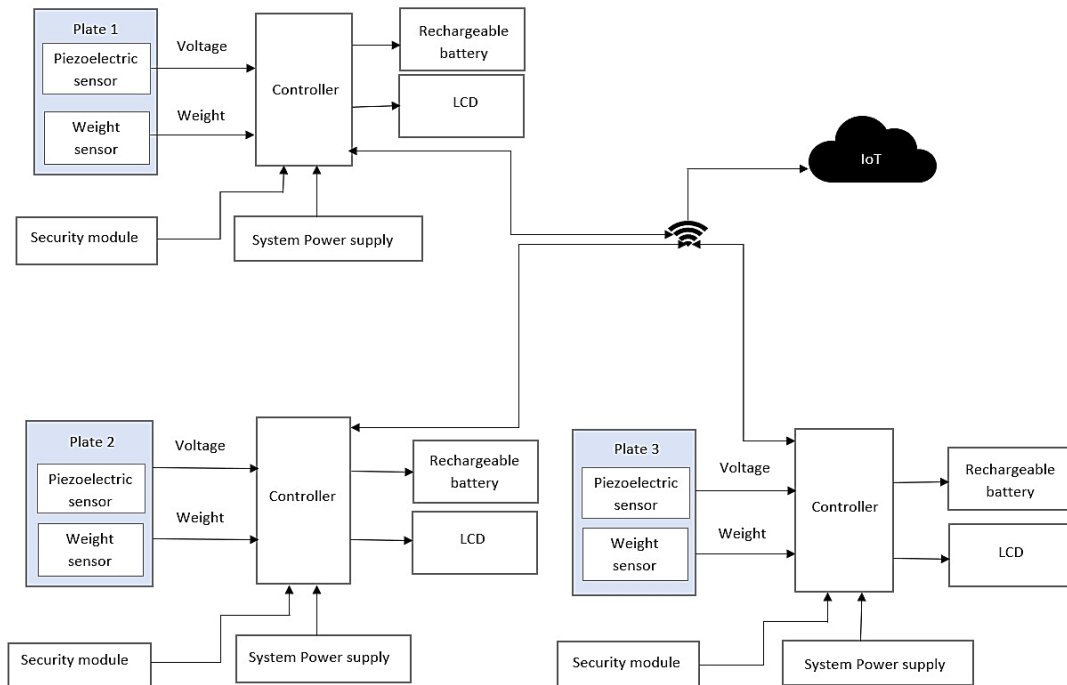


Figure 3.1: General block diagram of the system

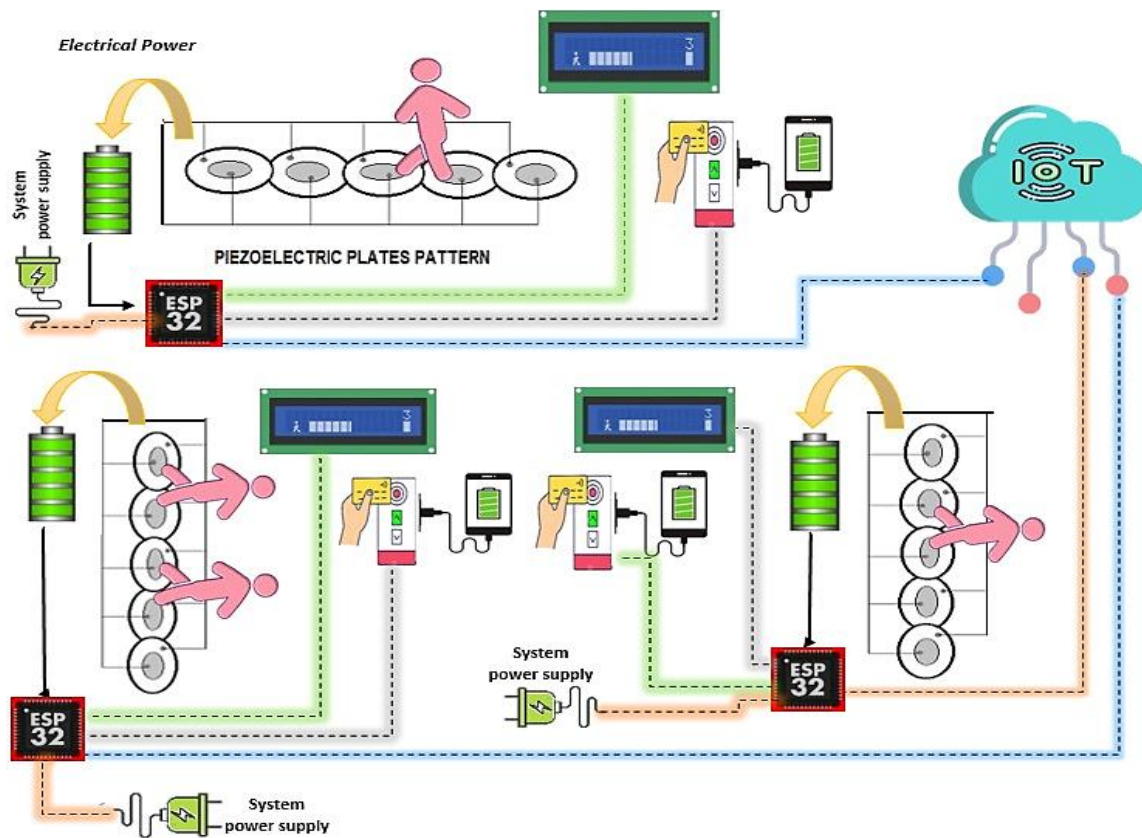


Figure 3.2 Conceptual diagram of the system

3.4 Algorithms and Methodologies

- **Flow chart**

Figure 3.3 shows the flow chart of the set up mode, the controller will be supplied with power, then the LCD work and a welcome message will displayed on it.

Figure 3.4 shows the flow chart of power generation mode, the human make a pressure on the plate and the generate voltage form the pressure will be stored in the battery, the load cells will measure the amount of weight on the plate, also the amount of voltage and the weight will be displayed on the LCD and uploaded it to the cayenne cloud.

Figure 3.5 shows the flow chart of power provision mode, the user should connect the USB cable to charge also the user should passed his/her card to determine if he/she authorized or not. If the user authorized the charging circuit will be open and he/she must passed the card again to prevent the other people to exploit the opening of the circuit, if not, the circuit will still close.

The serial number of card and the status of user's authority will be displayed on the LCD

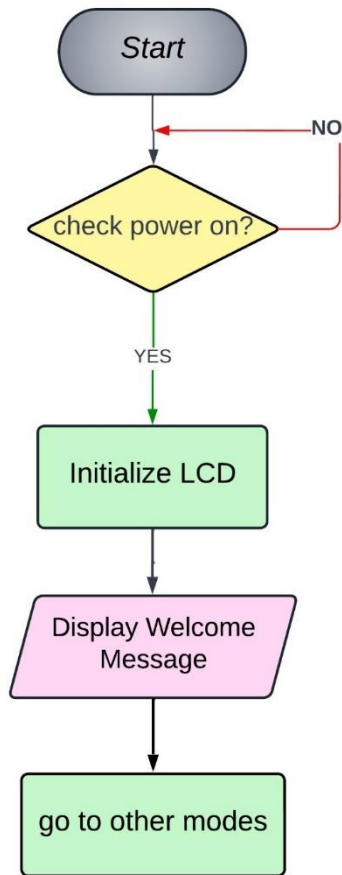


Figure 3.3: flow chart of setup mode

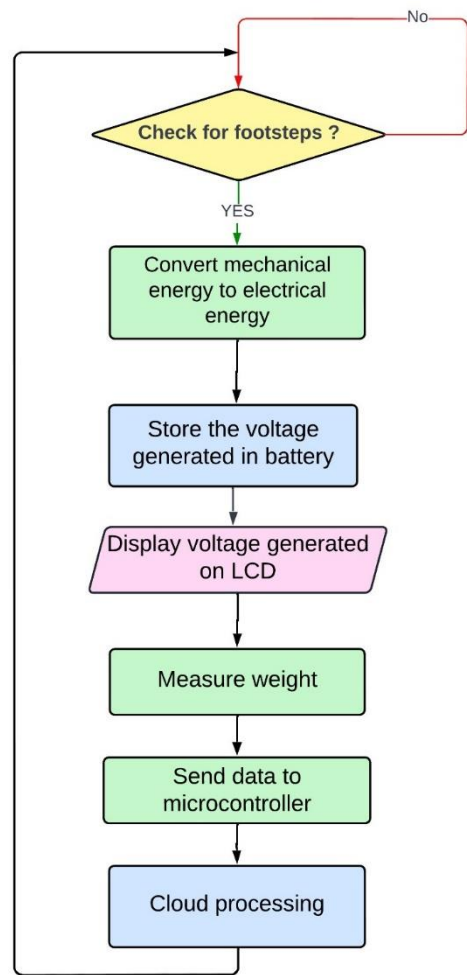


Figure 3.4: flow chart of power generation mode

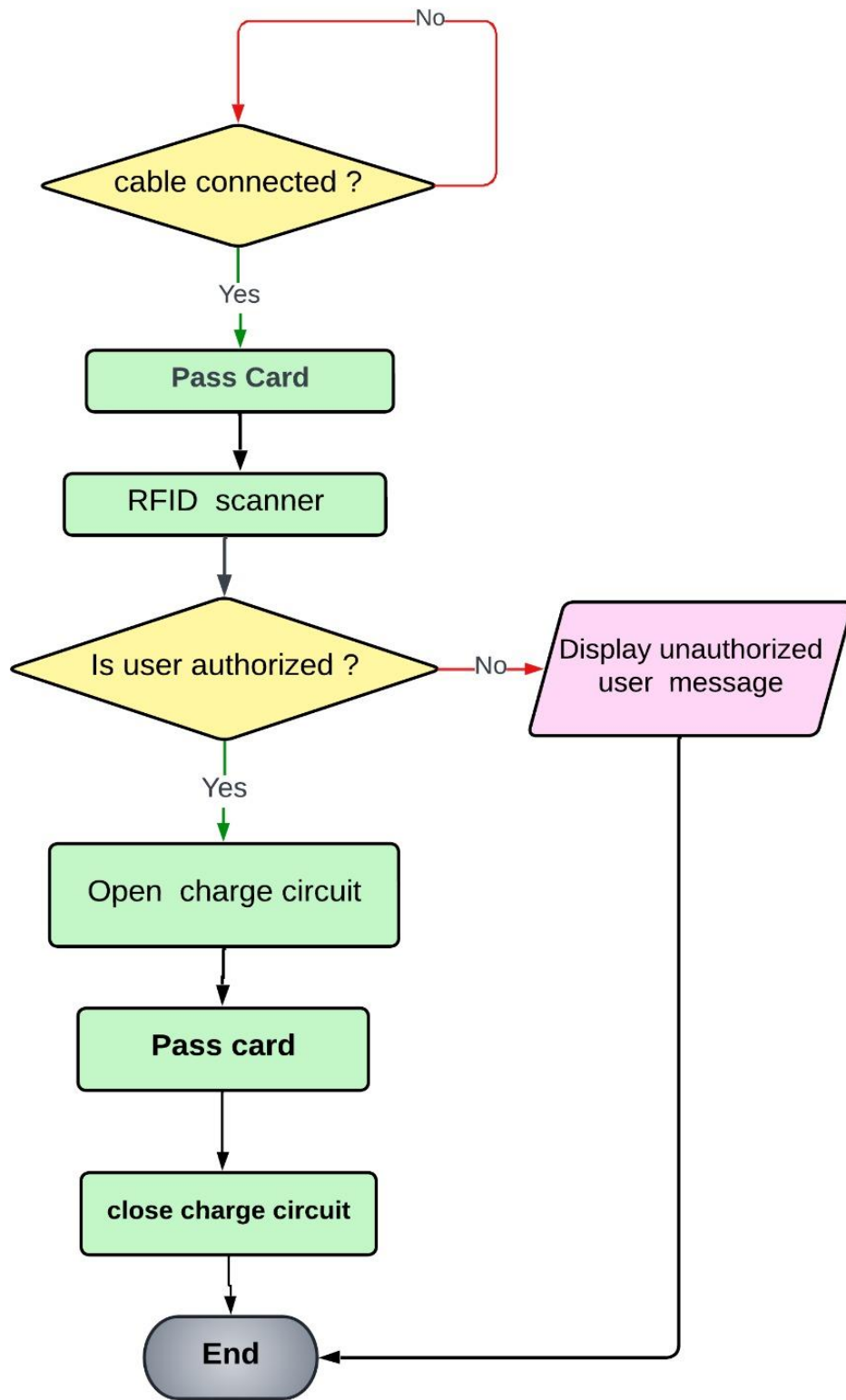


Figure 3.5: flow chart of power provision mode

- **Sequence Diagram**

Figure 3.6, figure 3.7 and figure 3.8 show the sequence diagrams for the operation modes of the system.

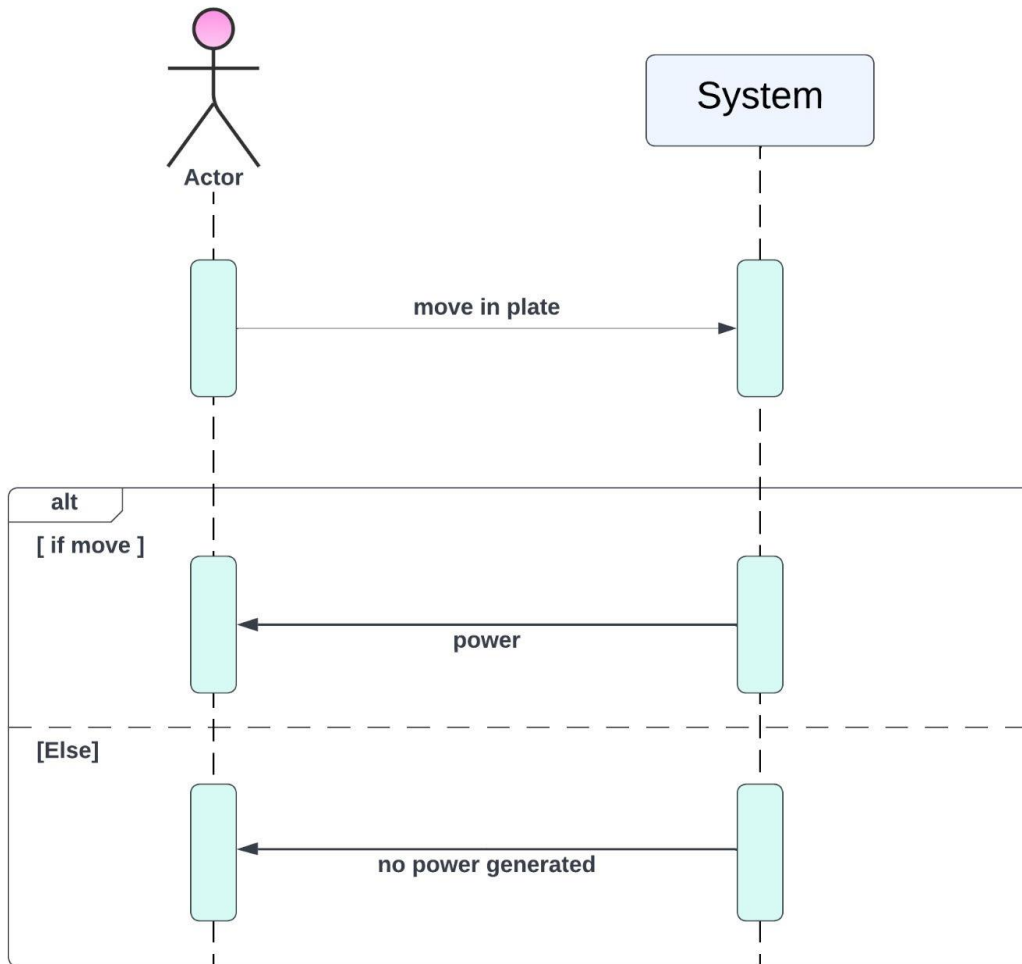


Figure 3.6: Sequence diagram of power generation mode

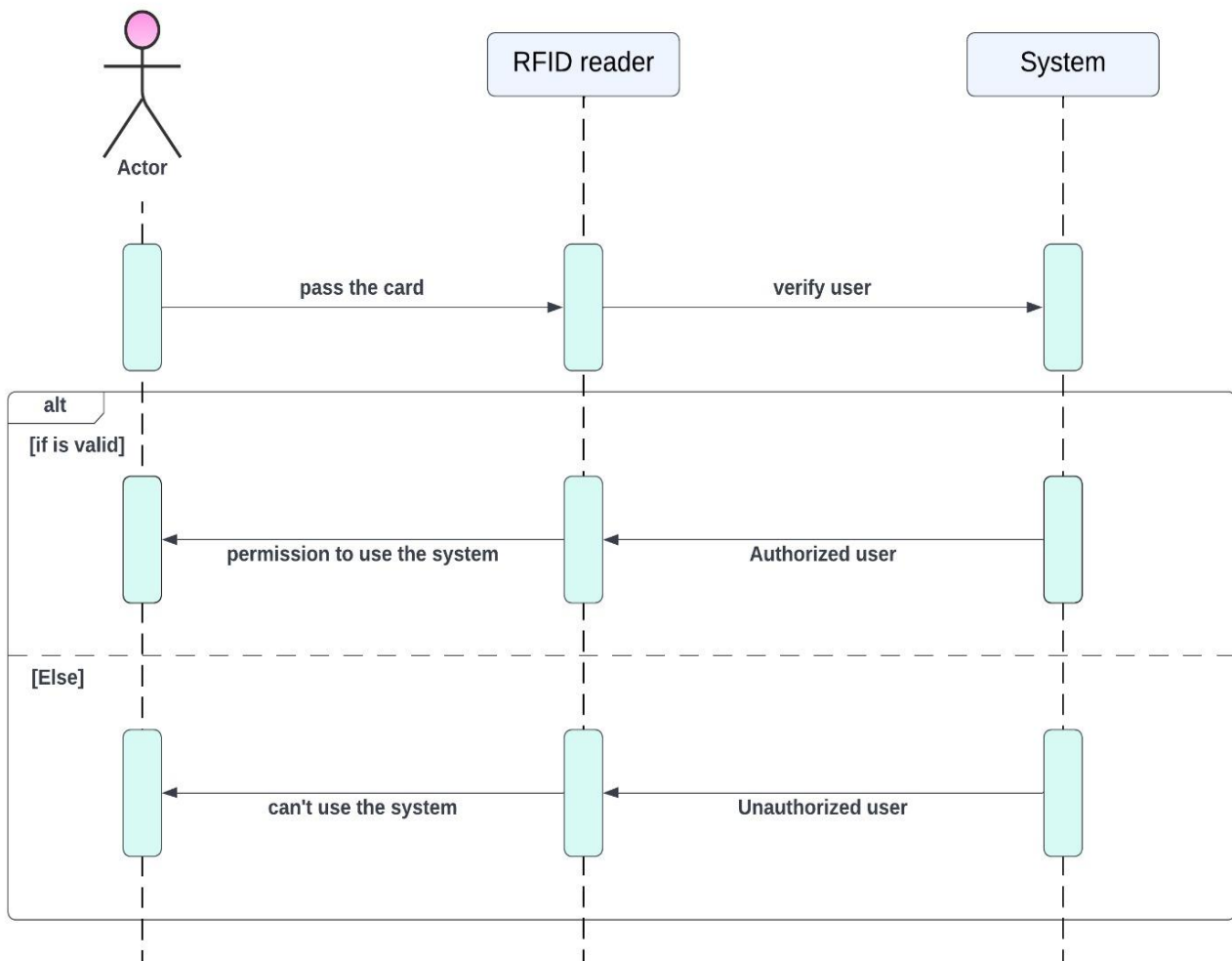


Figure 3.7: Sequence diagram of security module

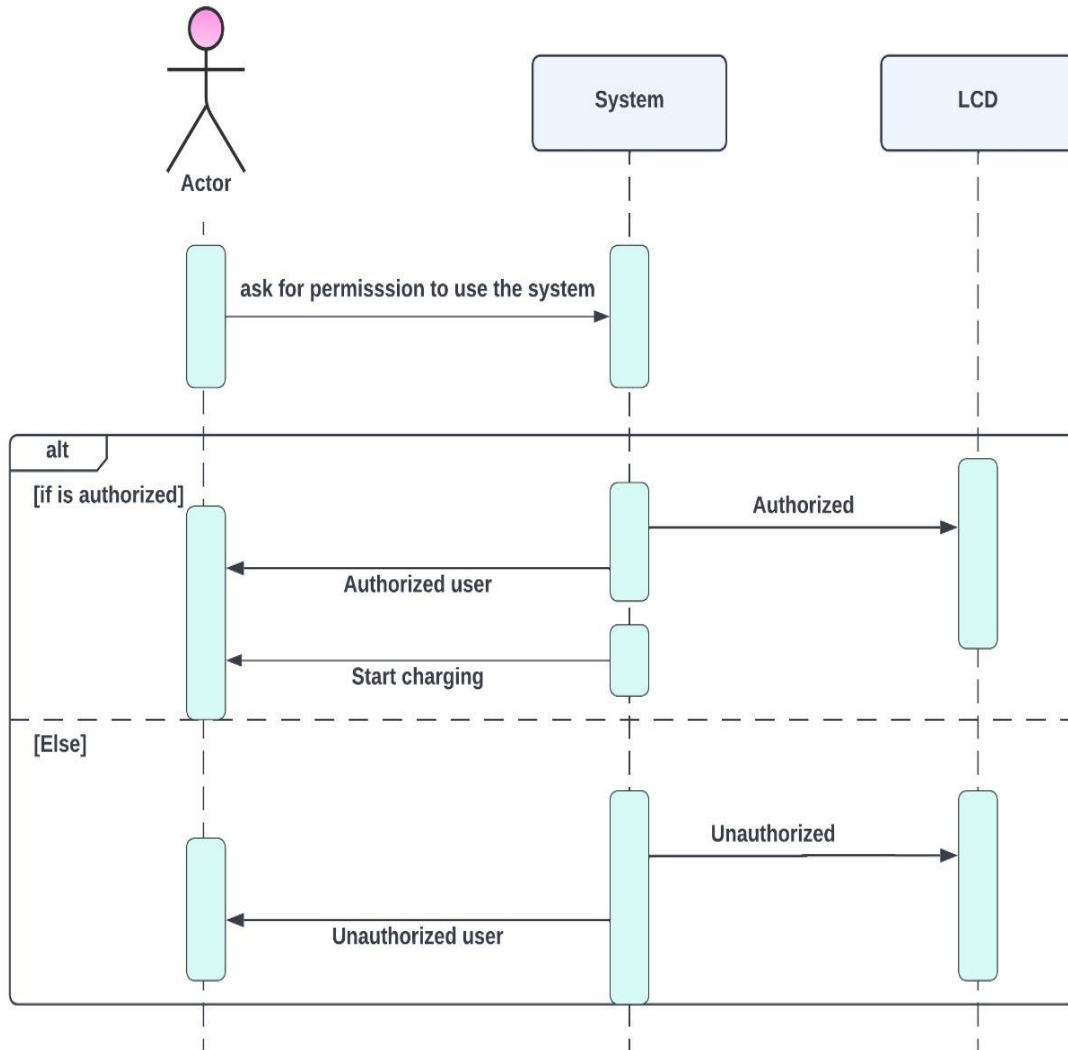


Figure 3.8: Sequence diagram of power provision mode

3.5 Schematic Diagram

The following figures show the schematic diagrams for main system components with their basic interfaces. Fig 3.9 shows schematic diagram of storage and generation circuit where the rectifier was used to convert the AC voltage from piezoelectric to DC voltage to be stored in battery, also we used voltage sensor to measure the DC voltage after it was converted and the diode to

prevent the voltage sensor takes the generated voltage so it will be assured that all the generated voltage will stored in the battery.

Fig 3.10 shows schematic diagram of LCD where the interface was used to limit the number of pins that is connected with the controller ESP32.

Fig 3.11 shows schematic diagram of load cell where the interface was used to be connected directly with the controller ESP32.

Fig 3.12 shows schematic diagram of provisioning circuit, relay sensor was used as a switch to open/close the charging circuit for the user to be able to charge any device based on the authority status of the user.

Fig 3.13 shows schematic diagram of RFID module, and fig 3.14 shows schematic diagram of whole system.

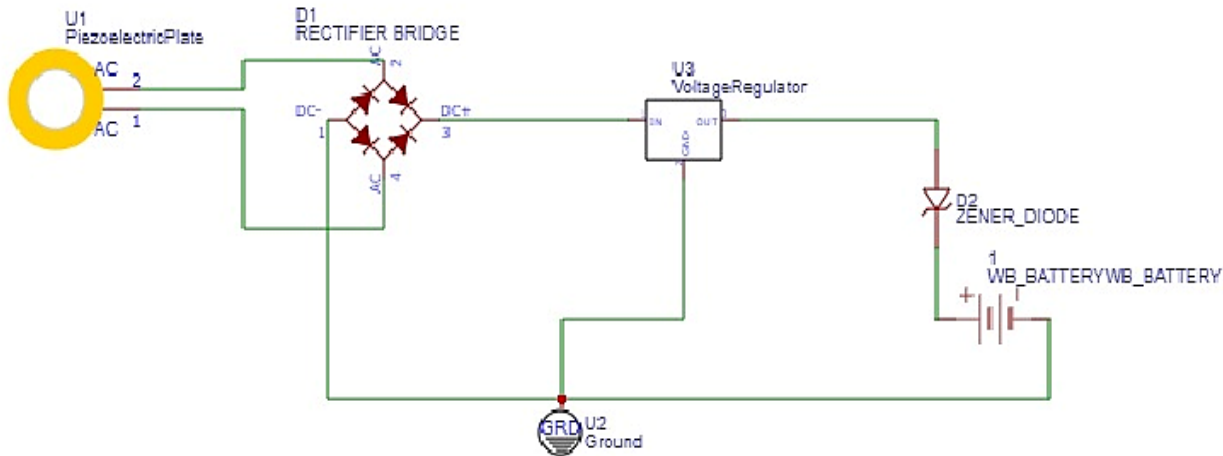


Figure 3.9: Schematic diagram of storage and generation circuit

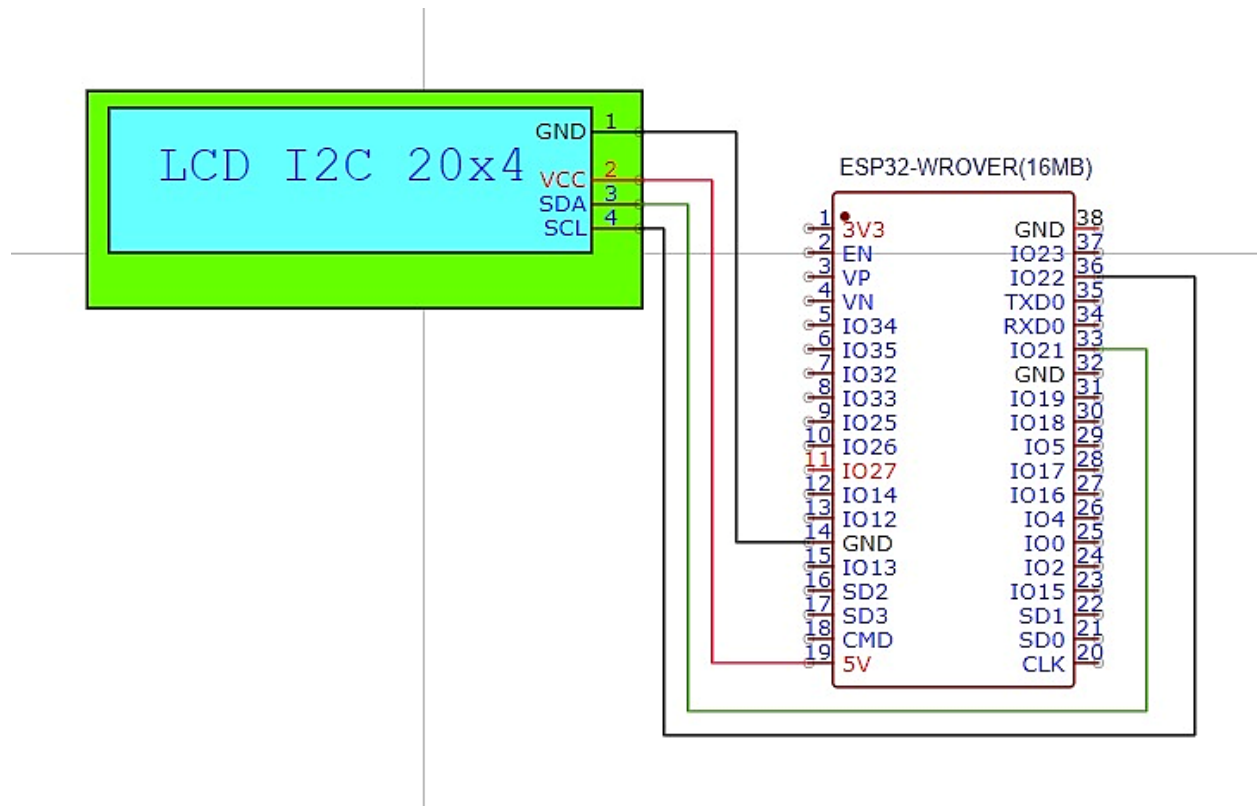


Figure 3.10: Schematic diagram of LCD

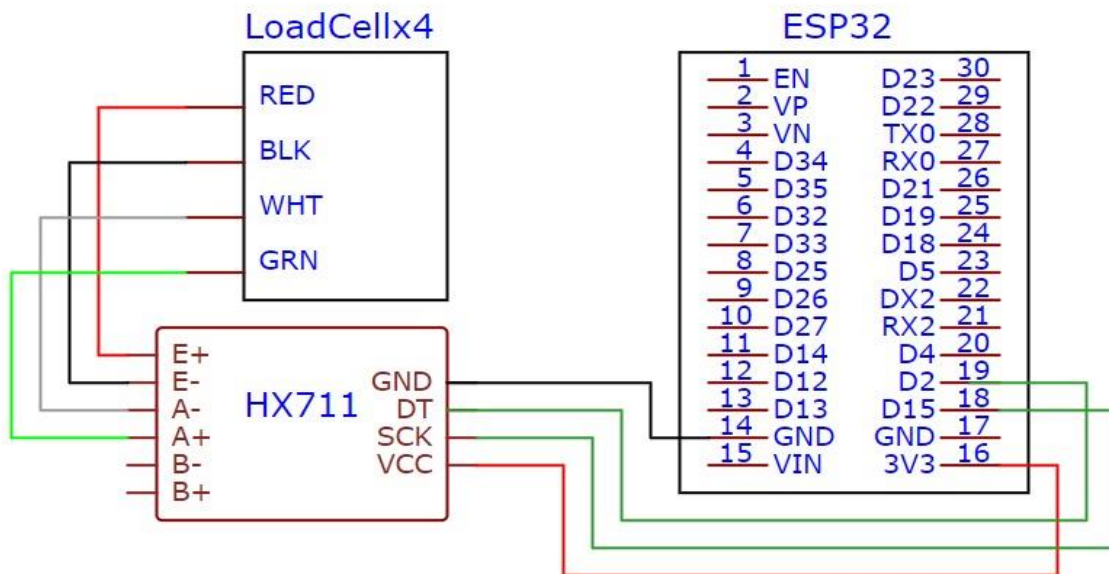


Figure 3.11: Schematic diagram of load cell

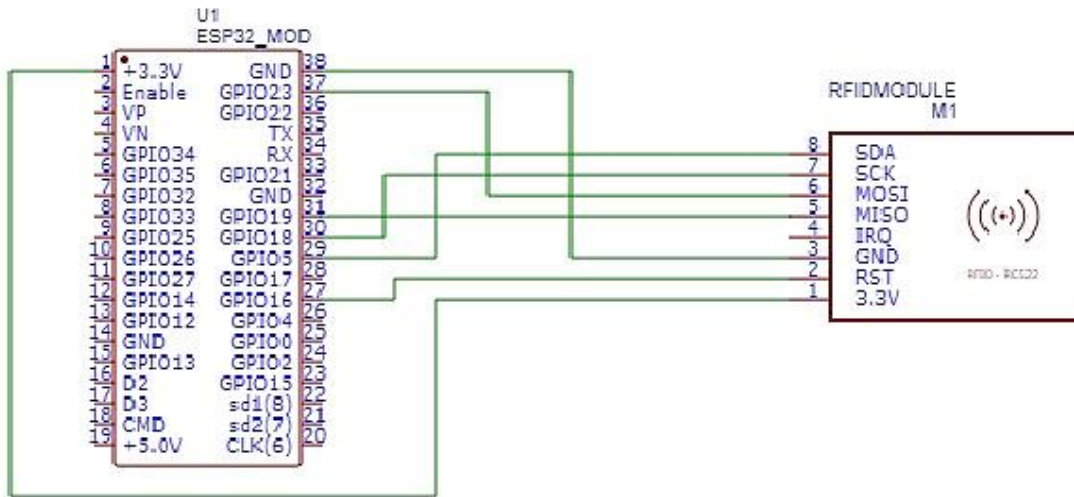


Figure 3.13: Schematic diagram of RFID module

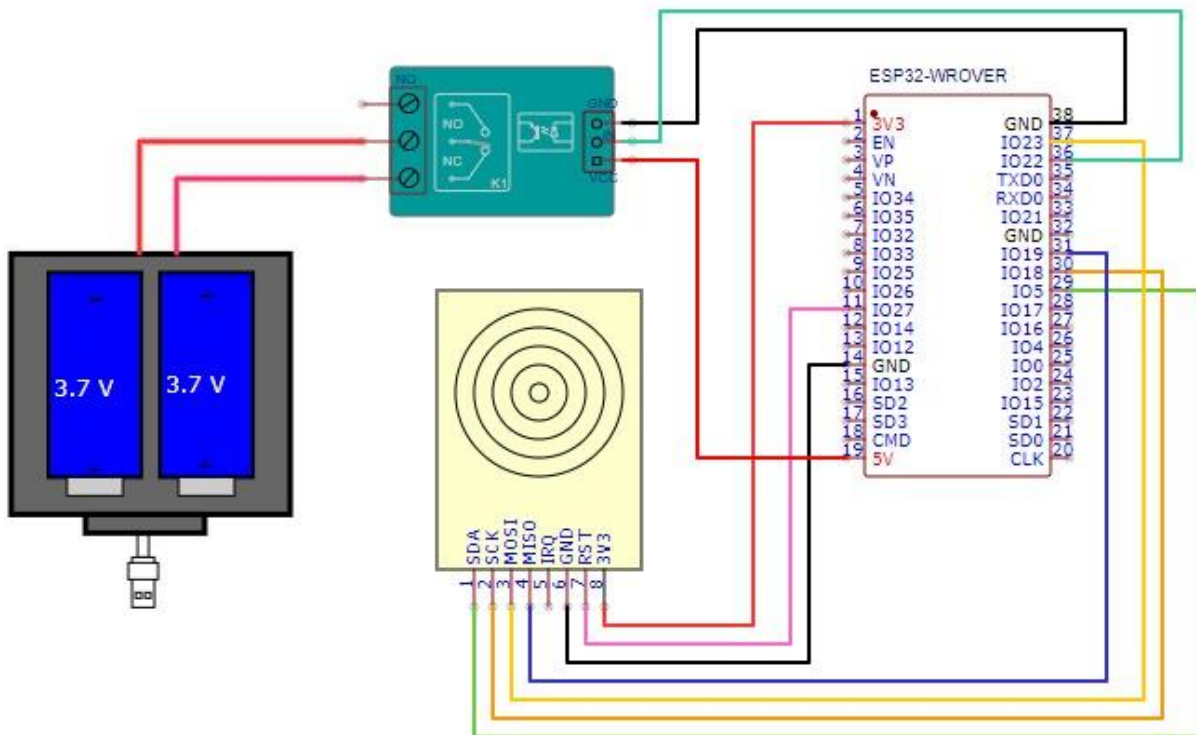


Figure 3.12: Schematic diagram of provisioning circuit

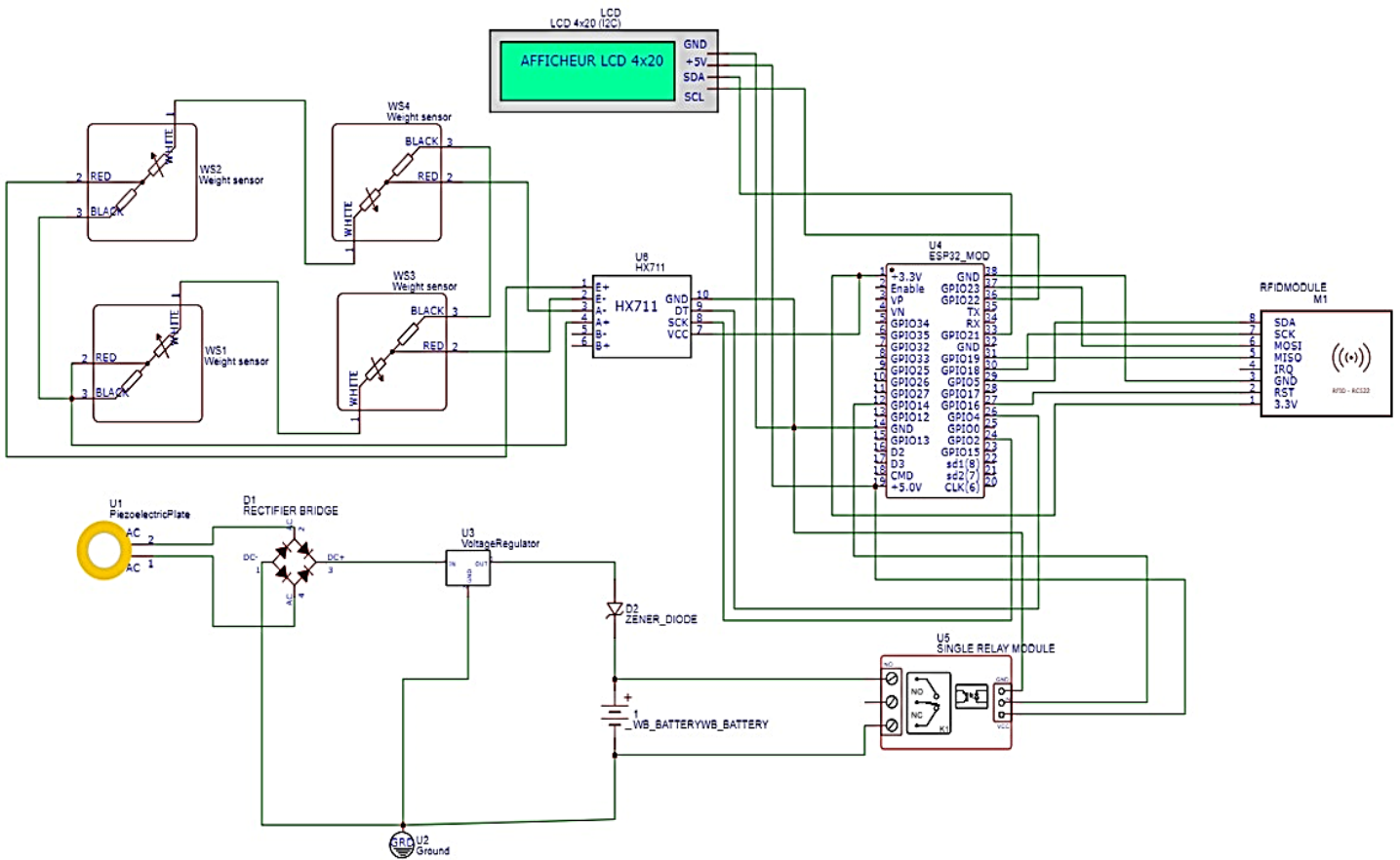


Figure 3.14: Schematic diagram of the whole system

3.6 Summary

In this chapter, we discussed the system hardware and software components with their alternatives. The conceptual description of the system and the general flow of the system with all necessary diagrams are presented, too.

Chapter four

System implementation

4.1 Preface

This chapter provides an overview of the software and hardware implementation, issues and challenges related to the implementation.

4.2 Hardware implementation

4.2.1 Piezoelectric implementation

8 piezoelectric sensors which is the same configurations for the piezoelectric sensor performed in [6] are used here; the 8 sensor was divided into 2 groups, each group includes 4 sensors connected in series and then the 2 groups are connected in parallel as shown in figure 4.1.

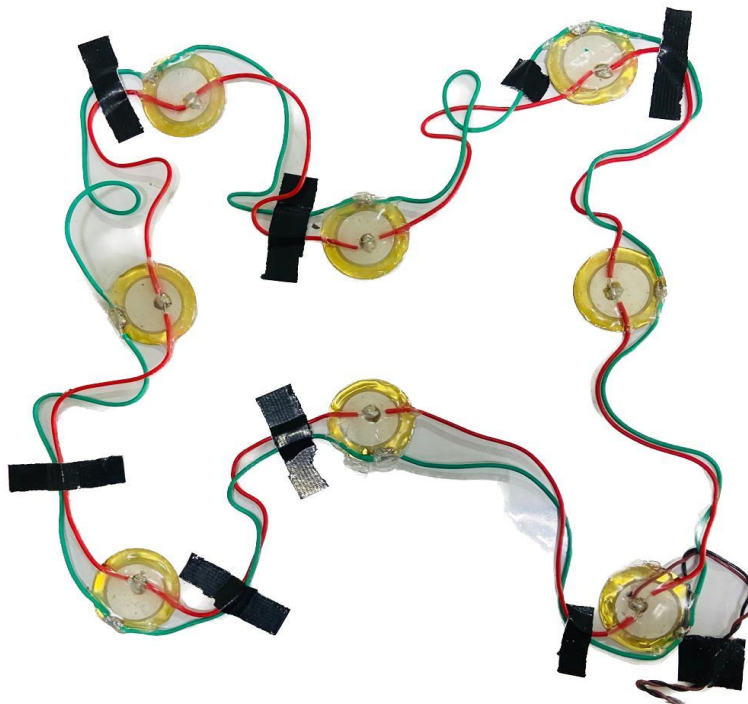


Figure 4.1 configuration of piezoelectric sensor

4.2.2 Load cells implementation

To measure the weight of a person who will walk on the plate, we needed 4 of 50 kg load cells. Since each load cell has three wires (red, black, and white), it was necessary to

determine which of these wires is the middle one by measuring the resistance value between white and black, which was 2 K Ω , red and white, which was also 1 K Ω , and black and red, which was also 1 K Ω . This indicates that the red wire is the middle one, so the black wires in each load cell connected with the black from the other load. We have four poles: A+, A- will serve as measurement wires, and E+, E- will serve as power wires. In order to connect the previously mentioned 4 poles with the esp32 microcontroller, we also need the HX711 amplifier module as shown in figure 4.2.

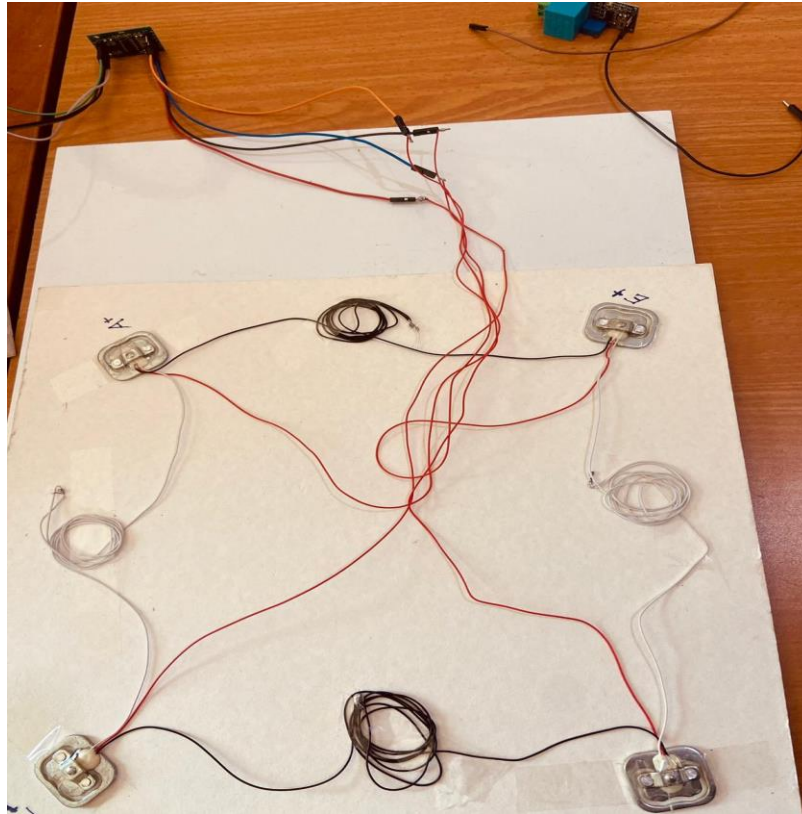


Figure 4.2 load cells configuration

4.2.3 Security module implementation

To achieve security in our system, we used the RFID module. The first component of RFID is the reader, which is attached to the ESP32 microcontroller. The second component is card that must be presented to the reader, then we passed the card in front of the reader.

As shown in figure 4.3, the reader was connected with ESP32.

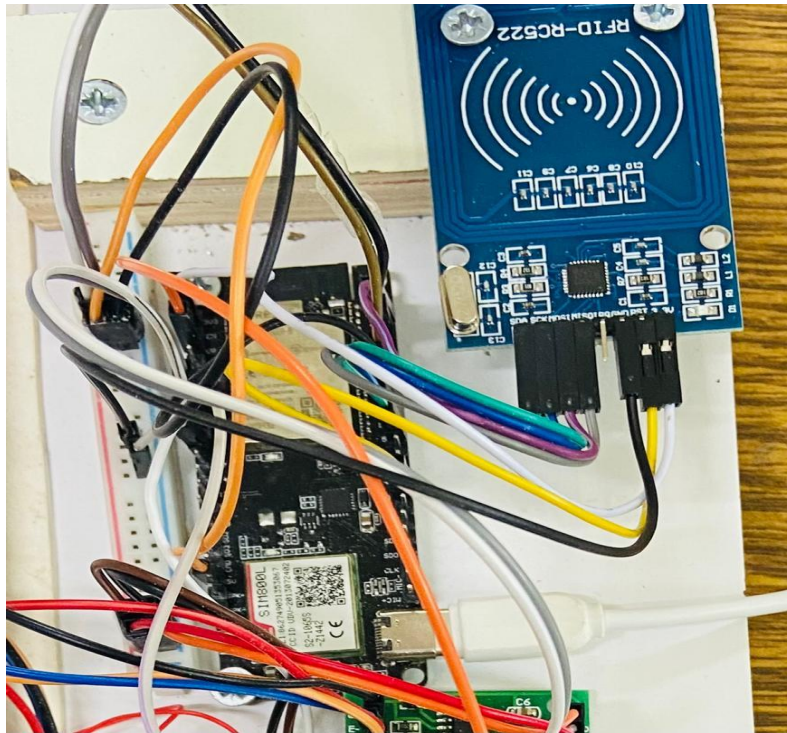


Figure 4.3: RFID connection

4.2.4 LCD implementation

To display the required information [amount of generated voltage, weight and status for authorizing], we used 20x4 LCD and connected to an ESP32 controller using I2C interface which converts the LCD's 16 lines into 4 lines in order to limit the number of pins that must be connected to the controller as shown in figure 4.4.



Figure 4.4: LCD connection

4.2.5 Storage circuit implementation

To store the generated voltage in rechargeable battery we built an integrated circuit that include the following electrical elements:

- Full bridge rectifier to convert the AC generated voltage to DC voltage to match the voltage stored in rechargeable battery.
- Voltage regulator to keep the voltage in the circuit relatively closed to the desired value which is 3.7 volt. Any value less than 3.7 it will be considered as zero and it will not be stored, also any value more than 3.7 it will be cut to 3.7 volt.
- Piezoelectric sensor that we mentioned previously.

4.2.6 Provision circuit implementation

Using the pervious project[6], 8 piezoelectric sensors have been taken, 2 groups of 4 of them was connected in series and the two group with each other in parallel because it gives more output voltage[6].To charge from battery, the user must be authorized. To achieve this, we built simple circuit that merge between security module and storage circuit by using relay module that act as switch as shown in figure 4.5.

If user passed the card in front of the reader and he/she was authorized the relay module will open the charging circuit and the user can charge the device. To prevent the people who exploit the opening of circuit, user must passed the card again to close the circuit.

If the user was not authorized the relay module will not open the circuit.

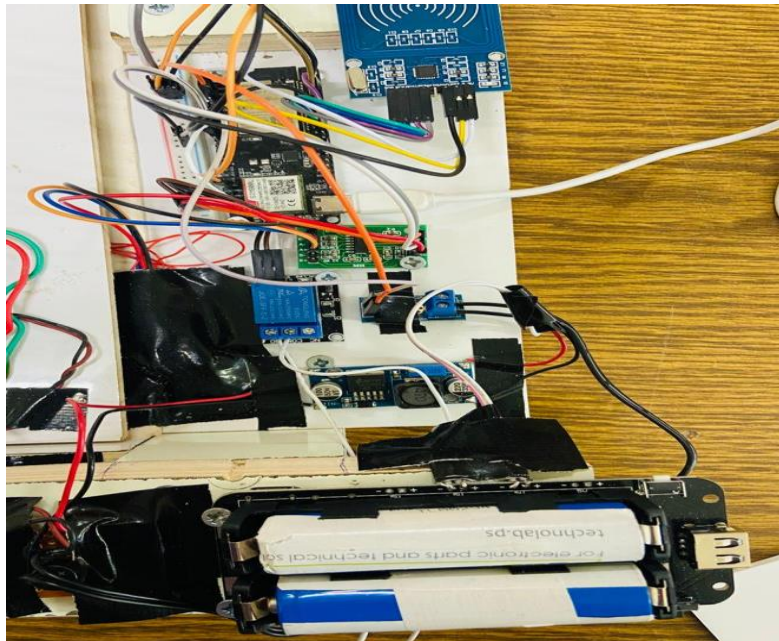


Figure 4.5 provision circuit

4.3 Software implementation

4.3.1 Libraries installation

Several libraries have to be installed on the Arduino IDE for the system to function such as:

- **CayenneMQTT** as a protocol to provides functions to easily connect to the Cayenne IoT project builder. This library is designed to work with Arduino, ESP8266 and ESP32 devices. With it you can send data to and receive data from Cayenne.
- **ESP32:** we need this library to define ESP32 as a board on the Arduino IDE to select the ESP32 type we have (ESP32 Wrover Module) and upload the code we need on it as shown in figure 4.6.
- **HX711_ADC** for the interface that connect between load cells and the controller.
- **I2C_LiquidCrystal** for the interface that connect between LCD and the controller.
- **MFRC522** for RFID to know the serial number of the card and use it later as a permission to the user to charge from the system.

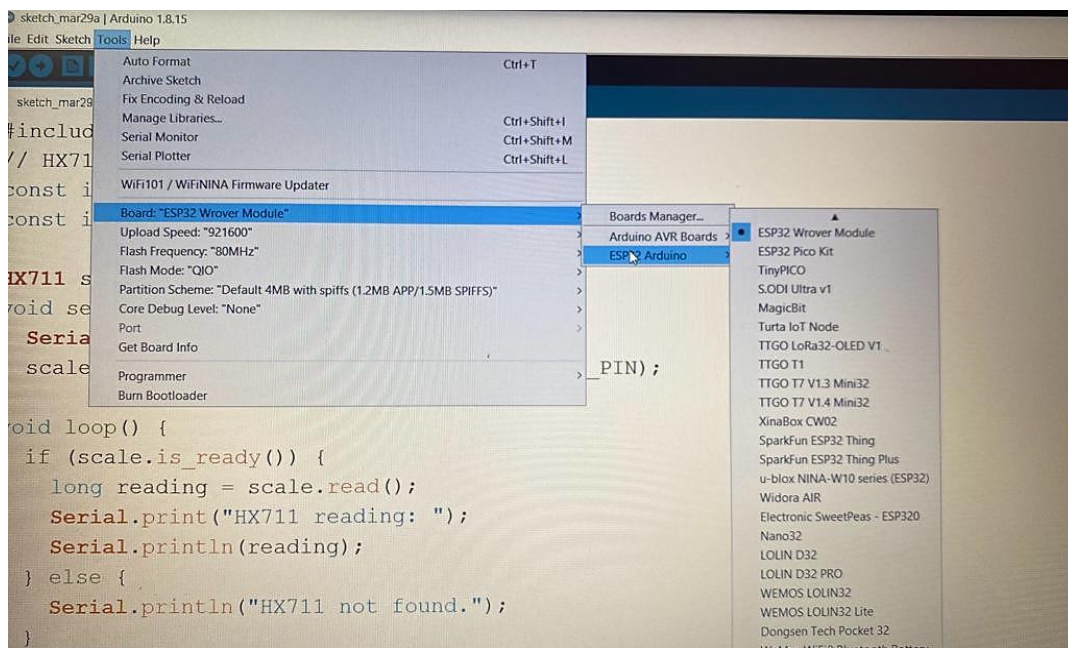


Figure 4.6 Select ESP32 board

4.3.2 Cloud setup

First, we had to create an account on Cayenne Cloud. We defined ESP32 on the account, the cayenne cloud provides us username, client id and password to change in the code related with MQTT library, also change the default network's name and password plus to our network as shown in figure 4.7.

The image shows a software development environment. At the top, there is a dark teal header with a 'Select Board' dropdown menu. Below the header, a file named 'ESP32.ino' is open, displaying C++ code for connecting an ESP32 to Cayenne. The code includes headers, defines debug and print macros, and sets up WiFi and MQTT credentials. The main functions are `setup()` and `loop()`. The `loop()` function calls `Cayenne.loop()` and `CAYENNE_OUT_DEFAULT()`.

Below the code editor is a cloud setup interface. It contains several input fields for MQTT configuration:

- MQTT USERNAME:** 16d96b30-953d-11e6-89ff-a79ab9c56619
- MQTT PASSWORD:** 2e10ce97-a4b4-40c6-9e1c-7864ef6a792b
- CLIENT ID:** d5c50a10-a08a-11e6-94d8-c10888b7cf0b
- MQTT SERVER:** va-staging-mqtt.mydevices.com
- MQTT PORT:** 1883

At the bottom of the interface, there is a status indicator: 'Waiting for board to connect...' and a note: 'Make sure...'.

Figure 4.7 Cloud setup

4.4 Implementation choices and challenges

- Three plates were designed, but only one plate was implemented due to time and financial constraints.
- It was supposed to use one 200 kg load cell. However, it needs much time to deliver so we replace it by 4 each of 50 kg load cells.
- We wanted to use 4 diodes to make bridge rectifier, but we found one piece that has this feature as built in with that circuit.
- Connecting LCD with no interface needs much pins that other components need so an interface used to limit the number of pins between LCD and ESP32.

4.5 Summary

In this chapter we reviewed the hardware and software implementation each component was fully explained and then we discussed the issues and challenges we faced during the implementation phase.

Chapter five

Testing and results

5.1 Preface

The testing of all system components and the results will be covered in this chapter.

5.2 Hardware testing

5.2.1 Unit testing

5.2.1.1 ESP32 testing

We connected ESP32 controller with laptop using suitable USB and uploaded GetChipID code from Esp32 library, then the ESP32 light up so that indicates that it worked.

5.2.1.2 Piezoelectric testing

By connecting the positive pole of the sensor with the positive side of the led and the negative pole with the negative side of led, we ensured that the sensor in the previous project worked. Then, we applied pressure to the sensor to cause the led to light up, demonstrating the sensor's ability to generate a voltage. Additionally, the multimeter was switched to the AC mode to measure the amount of AC voltage produced by each sensor. We discovered that applying pressure to one sensor causes it to produce a specific value that was identical to the values in previous project [6]. This value increased proportionally as more sensors came under pressure. Table 5.1 below contains these results.

Table 5.1 relation between number of sensors and output voltage

Number of sensors	Output voltage
1	1.3
2	2.1
3	3.2
4	4.4
5	5.7

5.2.1.3 Load cells testing

We connected the HX711 interface with load cells as:

- With the red wire from the first cell
- A+ With the red wire from the second cell

- With the red wire from third cell
- E+ With the red wire from fourth cell

Then we connected the pins of the interface with ESP32 as:

- DOUT with GPIO2, SCK with GPIO4, ground with GND and VCC with 3.3v.

After that we wrote the calibration code to calibrate the load cells using known masses. Finally we measured more masses and confirmed that it gives the closest value to the right weight of the mass as shown in table 5.2.

Table 5.2 load cell testing using different masses

Right value (kg)	Measured value (kg)	Absolute diff between values
63	62.83	0.17
58	58.10	0.1
74	74.01	0.01
49	48.92	0.08
71	70.91	0.09

We measured the error rate by using the equation 5.1 and it was 9%.

$$MAE = \frac{1}{n} \sum_{i=1}^n |x_i - x|$$

Equation 5.1: Absolute Error Formula

5.2.1.4 RFID testing (Security testing)

RFID tested by connecting with controller and we write code in the Arduino IDE to detect and receive information about each card's kind and NUID tag on the serial monitor after it was passed to the reader. All times were correctly succeed managed and the system gives a rate of 100%.

5.2.1.5 LCD testing

I2C interface was connected to the controller, then we tried to display some words to check that the LCD work correctly by writing appropriate code.

5.2.2 Block testing

5.2.2.1 Generation circuit testing

When we made a pressure on the piezoelectric sensor, an AC voltage was generated then we assured that the rectifier converted the AC voltage to DC by using the multimeter where was put in the DC voltage measurement mode, after number of steps we checked the battery was charged by using the multimeter in DC measurement mode. The circuit mentioned is shown in figure 5.1 and the testing results are listed in table 5.1.



Figure 5.1 Storage circuit testing

Table 5.3 testing results

Person 1	
Weight of step based on its strength	Amount of output voltage
0.23	0.09
7.29	2.91
15.71	6.28
22.91	9.16

40.16	16.06
55.62	22.25
Person 2	
Weight of step based on its strength	Amount of output voltage
1.09	0.44
3.72	1.49
15.60	6.24
36.78	14.71
66.08	26.43
Person 3	
Weight of step based on its strength	Amount of output voltage
4.70	1.88
19.69	7.88
47.82	19.13
66.35	26.54
70	28

- **Weight of step based on the strength:** when the human walks on the plate he/she will steps quickly and that mean he/she will not put her/his weight directly on the plate so the sensor will not measure the weight of a person, just weight of the step will be taken.

5.2.2.2 Provision circuit testing

After we test the storage circuit, we tried to charge from the battery to assure that it was charged, we needed to pass the RFID card on the reader to check if the user has authorized card or not. When we tried the authorized card the relay module open the charging circuit then we could charge the device we had from the battery, but when we tried the non-authorized card the relay module did not open the circuit so we couldn't charge the device, these 2 cases are shown in the figures 5.2 and figure 5.3 and the table 5.2 shows the results of security testing.

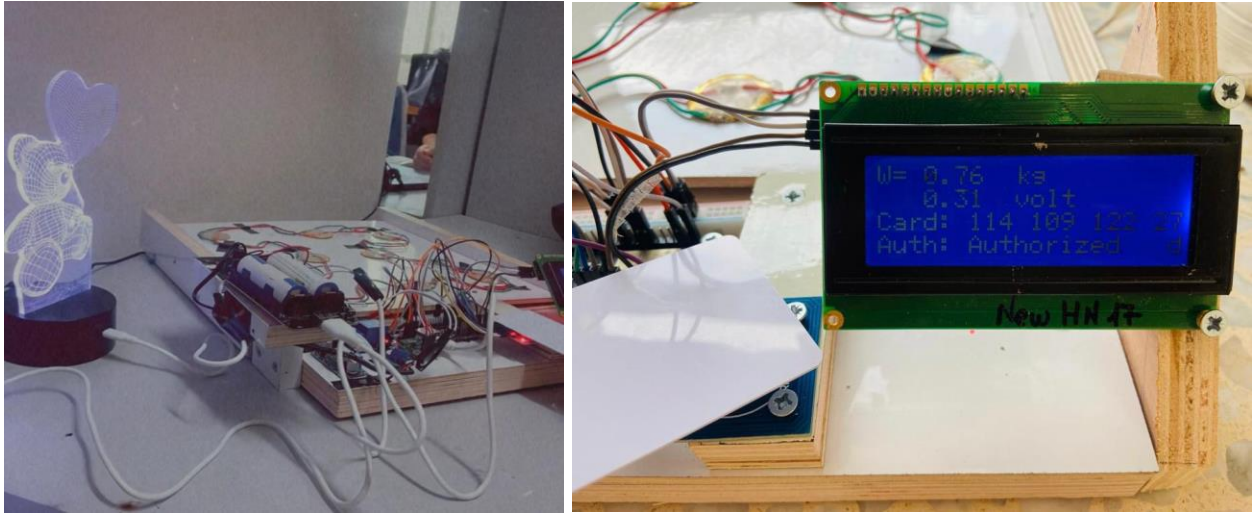


Figure 5.2 Authorized status

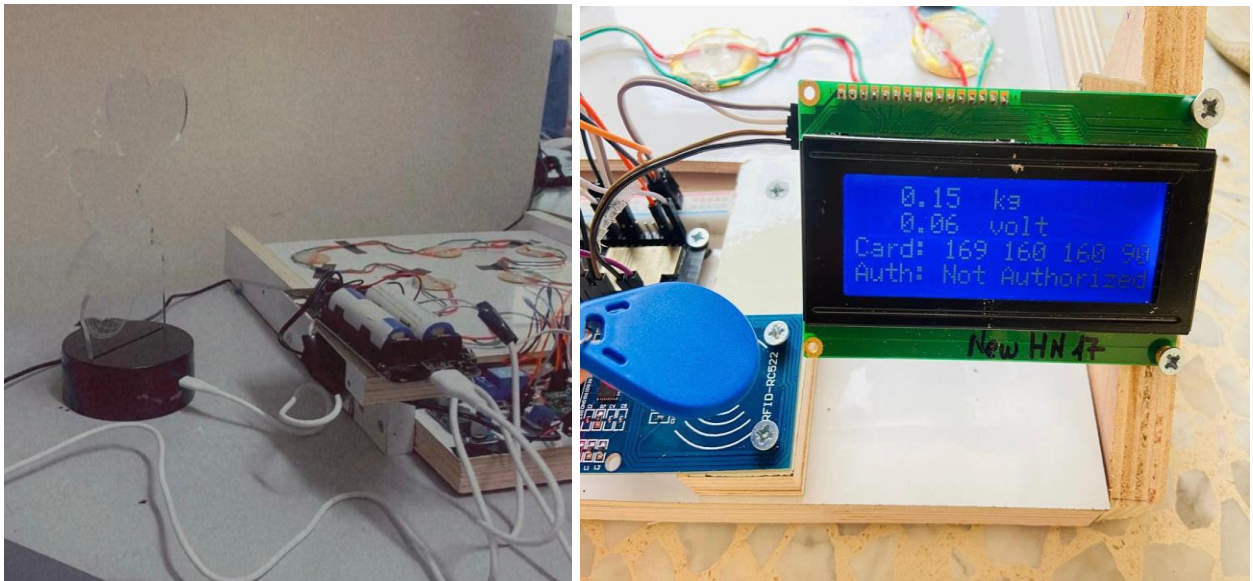


Figure 5.3 Unauthorized status

Table 5.4 results of security testing

# of attempts	Read card	Status of authority	Status of charging circuit
1	Yes	Authorized	Open
2	Yes	Non-authorized	Closed
3	Yes	Non-authorized	Closed
4	Yes	Authorized	Open
5	Yes	Authorized	Open

- The error rate of security was 0%, all attempts done successfully.

5.2.3 System testing

After we connected all the components with each other as shown in figure 5.4, we ensured that all components worked in the right way and gives the appropriate expected results.

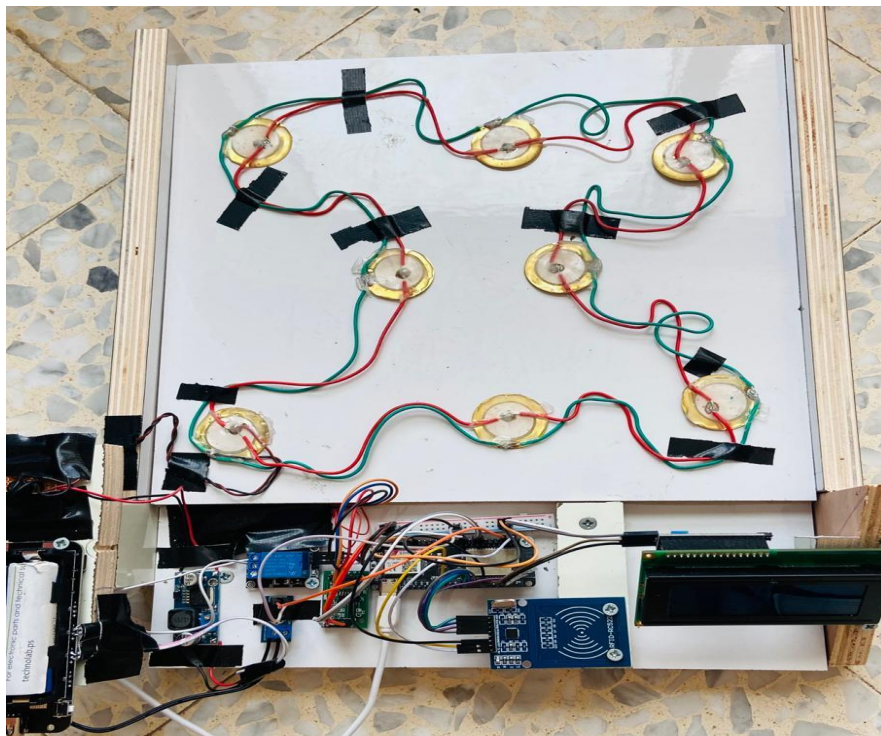


Figure 5.4 configuration of the whole system

5.4 Software testing

We tested cayenne cloud after we connected ESP32 with it by using MQTT protocol by uploading the load cells and voltage readings and the cayenne cloud can shows the readings in live so any change for the reading of values will directly changes in the cloud so we can decide the peak and off hours by the time given in cayenne as shown in figure 5.5 and figure 5.6.

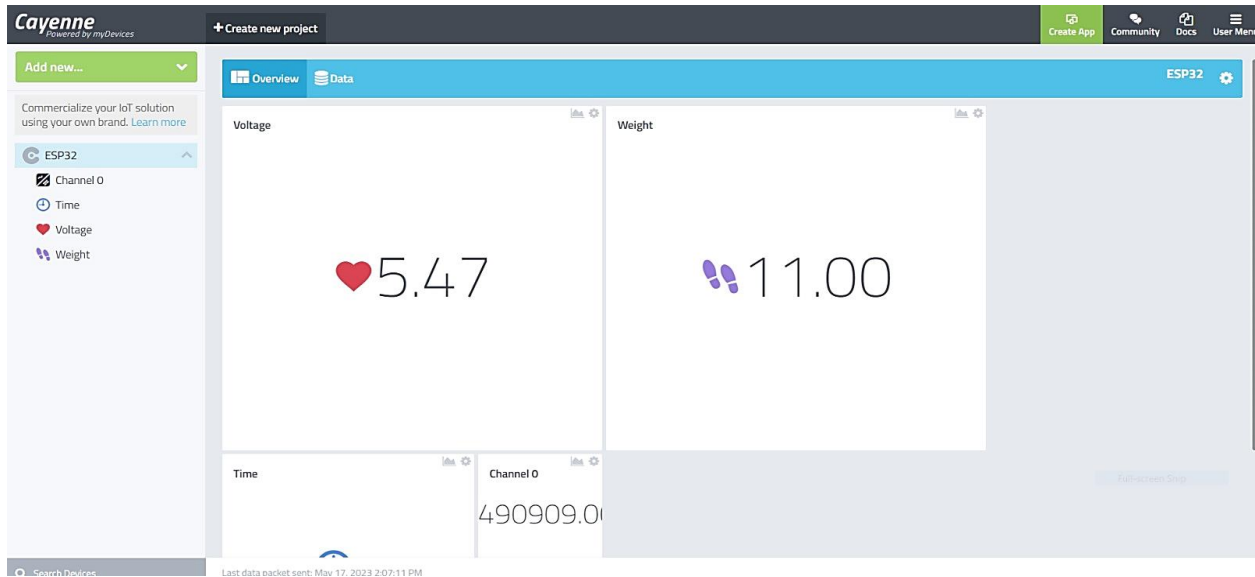


Figure 5.5 readings of weight and voltage

The screenshot shows the 'Data' view of the Cayenne IoT dashboard. It features a table with the following columns: 'Timestamp', 'Device Name', 'Channel', 'Sensor Name', 'Sensor ID', 'Data Type', 'Unit', and 'Values'. The table contains 17 rows of data, showing a sequence of readings for Voltage and Weight sensors. The 'Timestamp' column shows times from 2023-05-17 2:09:00 to 2023-05-17 2:09:11. The 'Values' column shows numerical readings ranging from 0.747 to 13.466. The interface includes a sidebar on the left with channel selection options and a top navigation bar with 'Overview' and 'Data' tabs. A 'Download' button is visible in the top right corner of the table area.

Timestamp	Device Name	Channel	Sensor Name	Sensor ID	Data Type	Unit	Values
2023-05-17 2:09:11	ESP32	2	Voltage	a5138ce0-f4a0-11ed-9ab8-d5...			13.466
2023-05-17 2:09:10	ESP32	1	Weight	ef6877f0-f49c-11ed-9ab8-d5...			33.666
2023-05-17 2:09:09	ESP32	2	Voltage	a5138ce0-f4a0-11ed-9ab8-d5...			19.722
2023-05-17 2:09:09	ESP32	1	Weight	ef6877f0-f49c-11ed-9ab8-d5...			49.306
2023-05-17 2:09:09	ESP32	0	Channel 0	b2a795c0-f4a2-11ed-9ab8-d5...			640132
2023-05-17 2:09:07	ESP32	2	Voltage	a5138ce0-f4a0-11ed-9ab8-d5...			2.064
2023-05-17 2:09:07	ESP32	1	Weight	ef6877f0-f49c-11ed-9ab8-d5...			5.161
2023-05-17 2:09:06	ESP32	2	Voltage	a5138ce0-f4a0-11ed-9ab8-d5...			3.052
2023-05-17 2:09:05	ESP32	1	Weight	ef6877f0-f49c-11ed-9ab8-d5...			7.630
2023-05-17 2:09:04	ESP32	2	Voltage	a5138ce0-f4a0-11ed-9ab8-d5...			0.545
2023-05-17 2:09:04	ESP32	1	Weight	ef6877f0-f49c-11ed-9ab8-d5...			1.364
2023-05-17 2:09:02	ESP32	2	Voltage	a5138ce0-f4a0-11ed-9ab8-d5...			3.232
2023-05-17 2:09:02	ESP32	1	Weight	ef6877f0-f49c-11ed-9ab8-d5...			8.081
2023-05-17 2:09:01	ESP32	2	Voltage	a5138ce0-f4a0-11ed-9ab8-d5...			4.833
2023-05-17 2:09:00	ESP32	1	Weight	ef6877f0-f49c-11ed-9ab8-d5...			12.083
2023-05-17 2:09:00	ESP32	1	Weight	ef6877f0-f49c-11ed-9ab8-d5...			1.867
2023-05-17 2:09:00	ESP32	2	Voltage	a5138ce0-f4a0-11ed-9ab8-d5...			0.747

Figure 5.6 results shown live

- Based on the data that was uploaded to the cloud, figure 5.7 shows the analysis on the data where it describes the relation between the weight and voltage.

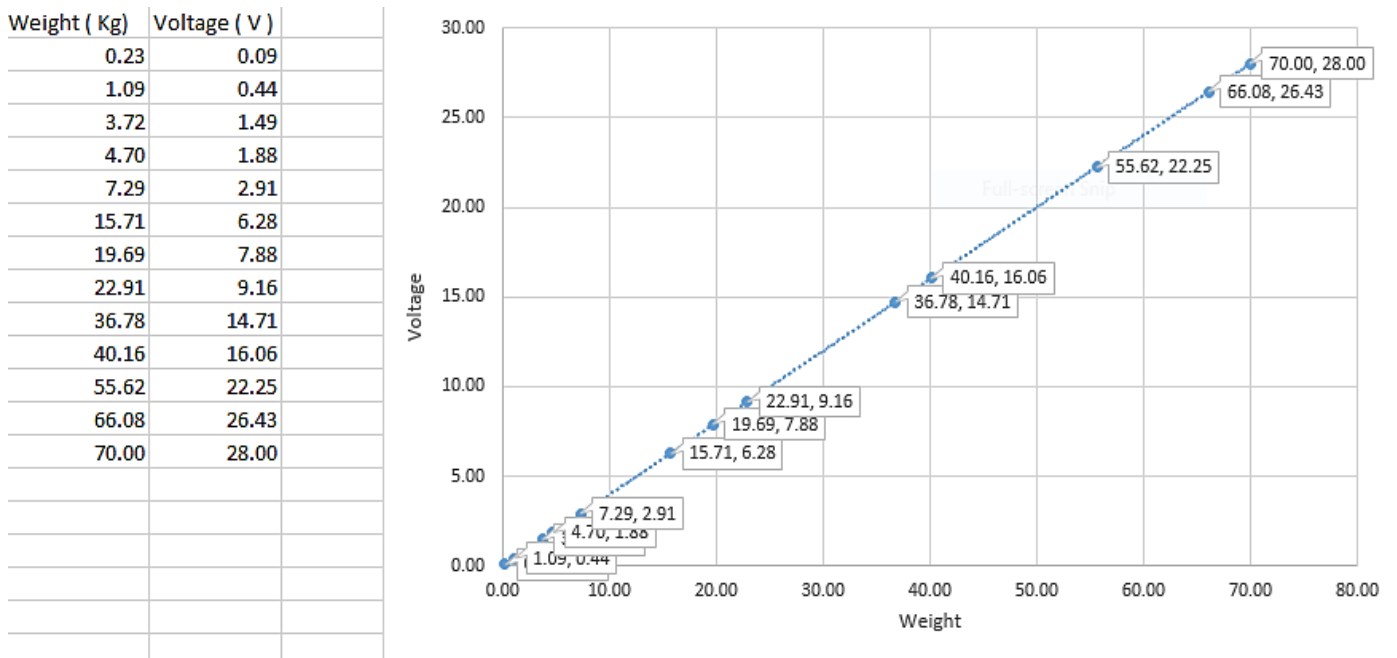


Figure 5.7 relation between weight and voltage

5.5 Summary

In this chapter we discussed the hardware and software testing.

Chapter six

Conclusion and future work

6.1 Preface

The chapter introduces a summary of the project, the future directions, and future work.

6.2 Conclusion

The main aim of the system is to generate electrical power from sustainable source of energy. The system was studied theoretically, analyzed, and proposed a suggested design. The objectives of the project were discussed, and the problem statement is raised with a short survey of previously related works. The system was explained in details, in terms of the components that will be used in implementing the system considering several alternatives for each component. In addition. The components interfaces are introduced.

One plate was implemented in the system, the system now is able to generate voltage by the fallen weight on the plate and stores it in a rechargeable battery. Only the authorized person could use the generated voltage and all these requirements tested successfully. The maximum voltage generated from one step was 28 volt.

Finally, all the readings of weight and voltage sensors uploaded to the cayenne cloud successfully where the obtained data was stored and analyzed.

6.3 Future work

In the future, we look forward to adding important features to the system, the most important can be supplies itself with the power that is generated from itself and the ability to add more plates to generate more voltage.

References

- [1] Renewable Energy and Energy Resources of the Future. New & Used Diesel Industrial Generators. (n.d.). Retrieved December 22, 2022, from https://www.generatorsource.com/The_Future_of_Power.aspx
- [2] Wikimedia Foundation. (2022, December 20). Internet of things. Wikipedia. Retrieved December 22, 2022, from https://en.m.wikipedia.org/wiki/Internet_of_things
- [3] IOT Technologies and protocols: Microsoft Azure. IoT Technologies and Protocols | Microsoft Azure. (n.d.). Retrieved December 22, 2022, from <https://azure.microsoft.com/en-us/solutions/iot/iot-technology-protocols/>
- [4] Avnet. (n.d.). Retrieved December 22, 2022, from <https://www.avnet.com/wps/portal/abacus/solutions/technologies/sensors/pressure-sensors/core-technologies/piezoelectric/>
- [5] Bacon, M., & Contributor, T. T. (2021, June 22). What is security? Security. Retrieved December 22, 2022, from [https://www.techtarget.com/searchsecurity/definition/security#:~:text=Security%20for%20information%20technology%20\(IT,otherwise%20known%20as%20threat%20actors.](https://www.techtarget.com/searchsecurity/definition/security#:~:text=Security%20for%20information%20technology%20(IT,otherwise%20known%20as%20threat%20actors.)
- [6] Badarin, A., & Zayed, W. (2018, May 1). Walk to generate power. DSpace Home. Retrieved December 22, 2022, from <https://scholar.ppu.edu/handle/123456789/6674>
- [7] College of Engineering - Prince Mohammad bin Fahd University. (n.d.). Retrieved December 22, 2022, from https://www.pmu.edu.sa/attachments/academics/pdf/udp/coe/dept/ee/senior%20design%20projects/smart_suitcase_report.pdf
- [8] Footstep Power Generation Project. Nevon Projects. (2018, December 26). Retrieved December 22, 2022, from <https://nevonprojects.com/footstep-power-generation-system/>
- [9] Arduino Mega 2560 REV3. Arduino Official Store. (n.d.). Retrieved December 22, 2022, from <https://store.arduino.cc/products/arduino-mega-2560-rev3>
- [10] Wikimedia Foundation. (2022, December 22). Raspberry Pi. Wikipedia. Retrieved December 22, 2022, from https://en.wikipedia.org/wiki/Raspberry_Pi
- [11] ESP32 series of modules. ESP32 Wi-Fi & Bluetooth Modules | Espressif. (n.d.). Retrieved December 22, 2022, from <https://www.espressif.com/en/products/modules/esp32>

- [12] Piezoelectric sensors information. Piezoelectric Sensors Selection Guide: Types, Features, Applications|Engineering360. (n.d.). Retrieved December 22, 2022, from https://www.globalspec.com/learnmore/electrical_electronic_components/passive_electronic_components/piezoelectric_devices/piezoelectric_sensors
- [13] LCD character display modules, character LCD module displays. (n.d.). Retrieved December 22, 2022, from <https://www.winstar.com.tw/products/character-lcd-display-module.html>
- [14] Types of USB ports: Compare different types of USB cables. Software Testing Help. (2022, December 5). Retrieved December 22, 2022, from <https://www.softwaretestinghelp.com/types-of-usb-ports-and-cables/#:~:text=White%3A%20These%20are%20usually%20the,B%20USB%203.1%20Gen%201>
- [15] Lawton, G. (2022, November 7). Active vs. passive RFID tags: Which to choose: TechTarget. ERP. Retrieved December 22, 2022, from <https://www.techtarget.com/searcherp/tip/Active-vs-passive-RFID-tags-Which-to-choose#:~:text=Two%20broad%20categories%20denote%20RFID,long%20life%20and%20small%20size>
- [16] Alloy steel flat thin force sensor load cell 150kg. Alloy Steel Flat Thin Force Sensor Load Cell 150kg - Buy Flat Thin Force Sensor,Flat Thin Load Cell,Load Cell 150kg Product on Alibaba.com. (n.d.). Retrieved December 22, 2022, from https://www.alibaba.com/product-detail/alloy-steel-flat-thin-force-sensor_62457134972.html
- [17] Factory price powerful 1.5 volt rechargeable battery cell 1.6V nickel zinc AA batteries with USB Type-C Port. Factory Price Powerful 1.5 Volt Rechargeable Battery Cell 1.6v Nickel Zinc Aa Batteries With Usb Type-c Port - Buy Rechargeable Batteries With Usb Port,1.6v Nickel Zinc Aa Rechargeable Battery,Usb C Aa Rechargeable Battery Product on Alibaba.com. (n.d.). Retrieved December 22, 2022, from https://www.alibaba.com/product-detail/Factory-Price-Powerful-1-5-Volt_1600698330572.html?s=p
- [18] Cloud computing services - amazon web services (AWS). (n.d.). Retrieved December 22, 2022, from <https://aws.amazon.com/>
- [19] Wikimedia Foundation. (2022, December 21). Google cloud platform. Wikipedia. Retrieved December 22, 2022, from https://en.wikipedia.org/wiki/Google_Cloud_Platform
- [20] Cayenne features - developer: Mydevices.com. Developer. (n.d.). Retrieved December 22, 2022, from <https://developers.mydevices.com/cayenne/features/>
- [21] Gupta, A. (2020, July 28). The world's most used renewable power sources. Power Technology. <https://www.power-technology.com/features/featurethe-worlds-most-used-renewable-power-sources-4160168/>

