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Subject

Design of an intelligent recycling machine

Publicly supported, the / / , in front of the jury composed of:

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Dedications:

*I, **BOUCHTOUT Zineddine**, dedicate this modest work with all my love and gratitude:*

*To my dear parents, **Abdenour** and **Akila**, for your unconditional love, unwavering support, and sacrifices since the day I was born. You have guided me, encouraged me, and helped me become the person I am today. No words can express my full gratitude towards you. I hope to one day be able to return even a small fraction of what you have given me.*

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الملخص

نظرًا لنمو السكان والاستهلاك الزائد، تبقى إدارة النفايات الحضرية تحديًا كبيرًا للحفاظ على الصحة العامة والبيئة من خلال ضمان التخلص السليم من النفايات وتقليل التلوث.

يتمحور هذا البحث في نهاية الدراسة حول تصميم وتنفيذ جهاز جمع مبتكر لجمع وفرز الزجاجات البلاستيكية وعلب المعادن، منتجات تستهلك على نطاق واسع والتي يمكن أن تكون التحصيل والفرز الصحيح لها تحديًا .يستخدم المشروع أجهزة استشعار متقدمة لإضفاء الذكاء الاصطناعي على سلة المهملات، مما يحول السلة العادية إلى نسخة ذكية، مبتكرة، وأكثر كفاءة.

بالإضافة إلى الفوائد البيئية، يقدم هذا النظام مزايا اقتصادية من خلال إعادة تدوير المواد القابلة لإعادة الاستخدام، بينما يعزز أيضًا الوعي الاجتماعي ومشاركة المجتمع في إدارة النفايات.

كلمات مفتاحية: آلة إعادة تدوير ذكية، مستشعر، إدارة النفايات، أردوينو، التحكم

Abstract

Due to population growth and overconsumption, urban waste management remains a major challenge to preserve public health and the environment by ensuring proper waste disposal and reducing pollution.

This end-of-study dissertation focuses on the design and implementation of an innovative collector to gather and sort plastic bottles and metal cans, widely consumed products for which proper collection and sorting can be challenging. The project utilizes advanced sensors to give the trash can artificial intelligence, transforming an ordinary bin into a smart, innovative, and more efficient version.

In addition to the environmental benefits, this system offers economic advantages through recycling reusable materials, while also promoting social awareness and community involvement in waste management.

Keywords: intelligent recycling machine, sensor, waste management, Arduino, control.

Résumé

En raison de la croissance démographique et de la surconsommation, la gestion des déchets urbains reste un défi majeur pour préserver la santé publique et l'environnement en assurant une élimination adéquate des déchets et en réduisant la pollution.

Ce mémoire de fin d'études porte sur la conception et la réalisation d'un collecteur innovant permettant de rassembler et de trier les bouteilles en plastique et les canettes métalliques, des produits largement consommés pour lesquels il est difficile d'assurer une collecte et un tri corrects. Le projet utilise des capteurs avancés pour conférer à la poubelle une intelligence artificielle, transformant ainsi une poubelle ordinaire en une version intelligente, innovante et plus efficace.

Outre les avantages environnementaux, ce système offre des avantages économiques grâce au recyclage des matériaux réutilisables, tout en favorisant la sensibilisation sociale et la participation communautaire à la gestion des déchets.

Mots clés : machine de recyclage intelligente, capteur, gestion des déchets, Arduino, commande.

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General introduction:

The rapid evolution of our society, characterized by increasing urbanization, higher consumption, and more dynamic lifestyles, has led to a significant increase in waste production. This trend poses major challenges in environmental management, requiring innovative and sustainable solutions to address this complex issue.

It is essential to implement ecological and intelligent solutions that can optimize the entire waste management process, from collection to disposal or recycling. Initiatives such as bottle and can recycling programs, like those observed in Germany with high collection rates, demonstrate the importance of effective recycling policies. However, it is crucial to go beyond these isolated measures and develop comprehensive and sustainable strategies to reduce waste production at the source, promote recycling, and raise awareness about responsible waste management for preserving our environment and health in the long term.

This research proposes an intelligent recycling machine that aims to revolutionize traditional recycling methodologies. The proposed machine integrates advanced sensors for material identification and sorting, coupled with automation to optimize processing efficiency. The technical specifications emphasize the use of sustainable materials and energy-efficient components to align with current environmental standards. The study aims to contribute to the field by advancing recycling technology, reducing contamination of recycled materials, and promoting a more sustainable approach to waste management.

This master's thesis consists of three chapters, each focusing on a specific aspect of the research on intelligent recycling machines. The first chapter provides an overview of waste types and current recycling options, highlighting the currently used waste treatment and recycling technologies. It also presents the key features of an intelligent recycling machine, as well as its technical requirements, challenges, and potential advantages and disadvantages, considering environmental, economic, and social perspectives.

The second chapter examines in detail the material and software resources required for designing, programming, and building an intelligent recycling machine. It presents and describes these resources, emphasizing their role and importance in the development process.

The third and final chapter of this master's thesis details the assembly and completion of the intelligent recycling machine, highlighting the technical challenges encountered throughout the study and design of this project.

The goal of this master's thesis is to explore how technological progress can be used to create innovative and sustainable waste collection solutions. We hope that this study will help better understand the challenges of waste management and provide ideas for creating ecological and intelligent waste collection systems, contributing to the preservation of our environment for future generations.

Chapter one:
Generalities on waste, recycling machines, and techniques

1. Introduction

The state of the art in the field of recycling machines and technologies reflects a constant evolution and a continuous quest for efficiency and sustainability. In a global context marked by growing concerns about the environment and resource management, the recycling industry plays a crucial role in the transition to a circular and sustainable economy. Advances in this field encompass a wide range of technologies, from automated sorting equipment to the most complex waste valorization processes.

2. Smart Recycling Machine:

A smart recycling machine is an automated equipment equipped with advanced technologies such as sensors, computer vision systems, and artificial intelligence algorithms, designed to efficiently sort, process, and add value to recyclable materials, contributing to optimizing the recycling process while minimizing costs and environmental impact.

3. Current state of recycling machines and technologies

The current state of recycling machines and technologies reflects a growing commitment to environmental sustainability and efficient resource management. Automated sorting equipment has reached an impressive level of sophistication, using advanced sensors, artificial intelligence algorithms, and robotic arms to effectively sort recyclable materials. These machines can distinguish a wide range of materials, improving the quality of recovered raw materials while reducing labor costs and increasing the efficiency of recycling processes.

Advances in mechanical and chemical technologies also allow for the transformation of a variety of waste into valuable raw materials, reducing dependence on natural resources and carbon footprint. However, challenges remain, particularly in terms of effective waste collection and separation, and public awareness of the importance of recycling. For recycling machines and technologies to reach their full potential, it is essential to continue investing in research, development, and innovation, while promoting policies and practices that support sustainable waste management on a global scale.

4. Types of Recycled Materials

A waste is a material or object considered useless and intended to be discarded. This can include anything from food waste to obsolete electronic equipment.

Here is a table that covers a wide variety of materials intended for recycling:

Paper and cardboard	Newspapers, magazines, office paper, cardboard boxes, etc.
Plastic	PET bottles, plastic packaging, plastic bags, etc.
Glass	Glass bottles, jars, windows, etc.
Metals	Aluminum, steel, iron, copper, etc.
Textiles	Clothing, fabrics, shoes, etc.
Organic waste	Food waste, garden waste, etc.
Electronics	Mobile phones, computers, electronic devices, etc.
Wood	Palettes, furniture, construction waste, etc.

Table I. 1: types of materials that can be recycled.

5. The treatment methods involved:

The treatment methods for different recyclable materials vary depending on their composition and characteristics. These methods are presented as follows:[1]

5.1. Step 1: Waste collection

Waste recycling begins with waste collection, which is typically done through selective collection in developed countries. Recyclable waste is sorted by the individuals who produce it, and only non-recyclable waste is taxed. The collected waste is sent to a sorting center to be mechanically and manually sorted before being processed. Broken glass is systematically removed to avoid injury risks. Non-recyclable waste is usually incinerated or buried in non-hazardous landfill sites.

Figure I. 1: Diagram showing waste collection and sorting.

5.2. Step 2: Transformation

After sorting, waste is transported to processing plants where they are integrated into specific processing chains. They enter these chains as waste and emerge as usable materials.

5.3. Step 3: Commercialization and Conservation:

After their transformation, recycled raw materials are used to manufacture new products that are then sold to consumers. At the end of their useful life, these products can be discarded and some of them can be recovered and recycled again, creating a continuous recycling cycle.

6. Identification of the main characteristics of a smart recycling machine:

A smart recycling machine is characterized by several features that enable more efficient management of recyclable materials. Here are some of the key characteristics that such a machine may have:

- Advanced sensors: The machine is equipped with sensors that allow for precise detection and classification of recyclable materials.
- Artificial Intelligence (AI) technology: AI is integrated to analyze data collected by the sensors, optimize sorting processes, and improve recycling accuracy.
- Automated sorting: The machine is capable of automatically sorting materials based on their type, color, or other characteristics, reducing the need for human intervention.
- Network connectivity: It can be connected to a computer network to enable real-time monitoring of operations, data management, and remote monitoring.
- Resource optimization: It is designed to maximize the use of available resources, thereby reducing operational costs and environmental footprint.
- User-friendly interface: It has a user-friendly interface that facilitates its use and allows for intuitive interaction with operators.
- Tracking and reporting: The machine is capable of generating detailed reports on quantities of recycled materials, operational performance, and other relevant metrics.

These features enable smart recycling machines to optimize recycling processes, improve operational efficiency, and contribute to more sustainable waste management.

7. Advantages and potential drawbacks of implementing a smart recycling machine:

7.1. Economic perspective:

- **Advantages:**

- Reduction in labor costs: Automation of the recycling process can reduce labor costs, as less manual work is required to sort and process recyclable materials.
- Resource optimization: By recycling materials more efficiently, companies can save on the costs of purchasing virgin raw materials, which can improve their profitability.
- Technological innovation: The adoption of smart recycling machines can stimulate innovation and competitiveness in the recycling industry, encouraging the development of new technologies and products.

- **Disadvantages:**

- High initial costs: The installation and maintenance of smart recycling machines can result in high initial costs, which can be an obstacle for some companies, particularly small and medium-sized enterprises.
- Technological dependence: Companies may become dependent on smart recycling machines, making them vulnerable to technical failures or system breakdowns, resulting in repair costs and production interruptions.

7.2. Environmental perspective:

- **Advantages:**

- Reduction in greenhouse gas emissions: Recycling materials instead of producing new materials from virgin raw materials can reduce greenhouse gas emissions associated with the extraction and processing of natural resources.
- Resource conservation: By recycling materials, natural resources such as water, trees, and minerals can be preserved, contributing to environmental sustainability.
- Waste reduction: Recycling materials reduces the amount of waste sent to landfills, reducing the environmental impact of solid waste.

- **Disadvantages:**

- Energy use: Some smart recycling machines may consume energy to operate, contributing to the overall carbon footprint of the recycling process.
- Electronic waste management: Smart recycling machines can generate additional electronic waste as they become obsolete or require upgrades, posing challenges in terms of appropriate waste management.

7.3. Social perspective:

- **Advantages:**

- Creation of skilled jobs: The adoption of smart recycling machines can create jobs in the fields of maintenance, repair, and management of recycling technologies, offering opportunities for skilled employment.
- Improvement of working conditions: Automation of the recycling process can reduce the need for manual labor, improving working conditions by reducing exposure to dangerous or unhealthy work environments.

- **Disadvantages:**

- Loss of unskilled jobs: Automation of the recycling process can lead to a reduction in demand for unskilled labor, which can have an impact on unskilled workers in the recycling industry.
- Inequalities in access to employment: The benefits of automation in the recycling process may not be evenly distributed, creating inequalities in access to employment and exacerbating socio-economic disparities.

8. Technical requirements and challenges related to the design and construction of a smart recycling machine:

Designing and constructing a smart recycling machine are complex tasks. Here are some of the main challenges and technical requirements associated with this process:

- Advanced sorting technologies: Integrating sophisticated sensors, computer vision systems, and artificial intelligence algorithms to enable precise and efficient sorting of recyclable materials.
- Reliability and robustness: Designing the machine to operate reliably in variable conditions, taking into account factors such as fluctuations in waste flow, variations in materials, and challenging work environments.
- Automation and control: Developing automated control systems to supervise and manage the machine's operations, ensuring optimal performance while minimizing the risk of errors or failures.

- Maintenance and repairs: Designing the machine to facilitate access to critical components, simplify maintenance operations, and enable quick repairs in case of need, to minimize downtime and maximize operational availability.
- Adaptability and scalability: Designing the machine in a modular and scalable manner, allowing for upgrades and adaptations to meet changing market needs and evolving regulatory requirements.
- Operational safety: Integrating safety devices and protective measures to prevent accidents and ensure the safety of operators and people working near the machine.
- System integration: Ensuring interoperability and seamless integration of the machine with other waste management equipment and systems, such as conveyors, storage systems, and tracking and tracing software.
- Environmental sustainability: Designing the machine with environmental sustainability principles in mind, using recyclable materials, minimizing energy consumption, and reducing greenhouse gas emissions throughout its life cycle.

9. Conclusion:

In conclusion, smart bins equipped with sensors and specified management represent a significant advancement in waste management. By enabling efficient sorting of plastic and glass bottles, these technologies contribute to reducing pollution and preserving the environment. Furthermore, they promote a more responsible use of resources by facilitating recycling and reusing materials. By investing in such innovative solutions, we are working towards a more sustainable future that respects our planet.

Chapter two:
Study of a Smart Recycling Machine

1. Introduction:

The objective of this chapter is to present a study on an intelligent recycling machine that can automatically sort waste that consists of plastic bottles and metallic cans. This chapter will provide a detailed description of the tools and software used for the implementation of this project. Through this in-depth study of the intelligent recycling machine, we hope to contribute to the advancement of environmentally friendly waste management solutions, offering a sustainable and efficient alternative for waste collection and tracking.

2. Description of resources used:

During the implementation of this project, several software and hardware tools were used, which will be presented in detail below:

2.1. Hardware:

2.1.1. Arduino:

Arduino is an open-source prototyping platform for electronic projects that allows users to create interactive projects by combining hardware and software that are easily accessible. It is based on flexible and easy-to-use hardware and software. Arduino boards are programmable microcontrollers that can be used to control physical objects by receiving information from various sensors and sending signals to various actuators. Arduino is widely used in various fields such as home automation, robotics, interactive art, portable devices, and more.

There are several types of Arduino boards, each with its characteristics and features. The most common and widely used is the famous Arduino UNO board. Other popular boards include the Arduino MEGA, Leonardo, Due, Nano, Pro Mini, and other special versions of Arduino boards adapted to specific needs such as wireless connectivity and IoT applications.

These Arduino boards differ mainly in their hardware specifications, performance, features, and capabilities. These differences are summarized in:

- Microcontroller: This is the heart of the board, and each board has its microcontroller, which differs in terms of performance.
- Number of pins: Each board has a specified number of analog and digital input/output pins, which determines the complexity and size of the project that can be realized.
- Size and shape: Arduino boards vary in size and shape. For example, the size of the UNO board is standard and suitable for several projects, while the size of the Arduino

Nano is much smaller and better suited for compact projects with limited space.

- Additional features: Some Arduino boards offer additional features compared to basic models. For example, the Arduino Leonardo has USB device emulation, which allows it to be recognized as a directly connected USB device on a computer.

Here is a description of the components and pins of the Arduino UNO board that we opted for in this project:

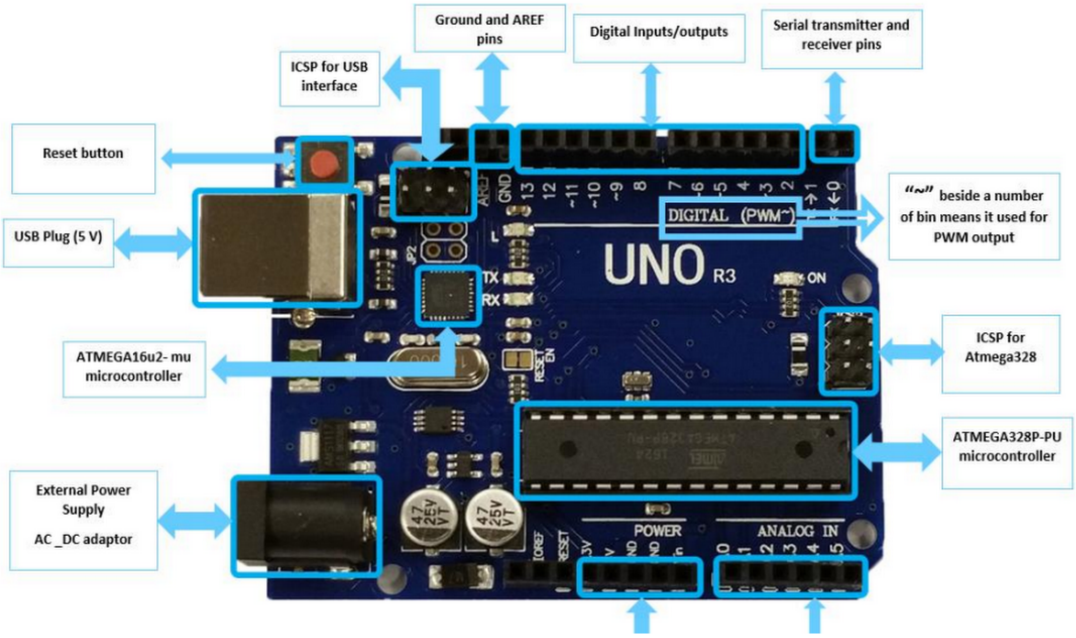


Figure II. 1: Arduino UNO pinout.

2.1.2. Sensors:

2.1.2.1. Presentation:

Information is an abstract quantity that specifies a particular event from a set of possible events. To be processed, this information must be carried by a physical medium, which is then called a signal. Here, we will discuss sensors, which are components of the acquisition chain in a functional chain. They allow for the acquisition of information on the behavior of the operating part and transform it into usable information for the control part.[2]

Figure II. 2: data acquisition chaine.

2.1.2.2. Types of sensors:

Sensors can be classified according to three essential criteria:

- Energy supply
- Output type
- Detection type

2.1.2.2.1. Energy supply:

- **Passive sensors:**

Passive sensors are those that generally require external energy to function. They can be modeled by an impedance, and a variation in the physical phenomenon being measured causes a variation in the impedance. Therefore, applying a voltage to these sensors is necessary to obtain a signal output.[2]

- **Active sensors:**

A sensor is properly considered active when the physical phenomenon used for the determination of the measure directly performs the transformation into an electrical quantity, which is a potential difference.[2]

2.1.2.2.2. Output type:

According to the type of output given by the sensor, it can be:

- **Analog sensor:**

The output of analog sensors is an electrical quantity whose value is a function of the physical quantity measured by the sensor. The output can take an infinite number of continuous values. The signal of analog sensors can be of the type:

- Output as a voltage.
- Output as a current.
- Graduated rule, dial, gauge... [2]

- **Digital sensor:**

the output is a sequence of logical states, the output can also take a large number of discrete values. This output can be of the type:

- Binary digital code.
- Train of pulses with a precise number of pulses or with a precise frequency.
- Fieldbus.[1]

- **Logical sensor:**

also called TOR (On or Off) sensors, whose output is a logical state represented by 0 or 1, it can only take these two values which in turn represent the high state and the low state of the electrical signal often taken as a tension (5V or 0V).[3]

2.1.2.3. Detection type:

According to the needs of use, there are sensors whose detection is done either:

- **With contact:**

where the sensor must physically and directly come into contact with a phenomenon to detect it.[2]

- **Without contact:**

where the sensor detects the phenomenon in proximity to it.

2.1.2.4. Sensor characteristics:

A sensor can be characterized according to many criteria, with the most common ones listed as follows:

- The physical quantity being measured.
- Response time.
- Range or measurement range: the possible variation of the quantity to be measured defined by a minimum value and a maximum value.
- Sensitivity: expresses the variation of the output signal in relation to the input signal.
- Accuracy.
- Linearity: in analog, the output values are proportional to the input values throughout the measurement range.
- Bandwidth: frequency intervals for which the response of a device is above a minimum.

- Resolution: the smallest variation in the input signal that produces a perceptible change by the sensor.
- Hysteresis: represents the delay of the effect on the cause, it is the property of a system that tends to remain in a certain state when the external cause that triggered the change has ceased.
- Operating temperature range.[3]

In the following, we present the various electronic components used in this project, detailing their principles of operation, characteristics, and illustrating their use through concrete examples.

2.1.3. Ultrasonic sensor HC-SR04:

2.1.3.1. Description:

The ultrasonic sensor HC-SR04 is a distance detection module that uses ultrasound to determine the distance of an object. It offers a non-contact detection range of 2cm to 400cm with a measurement resolution of 0.3cm and an effective measurement angle of 15°. The sensor emits a series of ultrasonic pulses at 40 kHz and waits for the reflected signal to calculate the distance based on the speed of sound.[4]

Figure II. 3: ultrasonic HC-SR04 sensor pinout.

2.1.3.2. Specifications and limits:

Parameter	Min	Type	Max	Unité

Supply voltage	4.5	5	5.5	V
Idle current	1.5	2	2.5	mA
Operating current	10	15	20	mA
Ultrasonic frequencies	-	40	-	kHz

Table II. 1: specifications and limits [4].

2.1.3.3. Principle of operation and distance measurement:

To trigger a measurement, a "high" pulse (5V) of at least 10 µs must be presented on the "Trig" input. The sensor then emits a series of 8 ultrasonic pulses at 40 kHz and waits for the reflected signal. When it is detected, it sends a "high" signal on the "Echo" output, the duration of which is proportional to the measured distance.

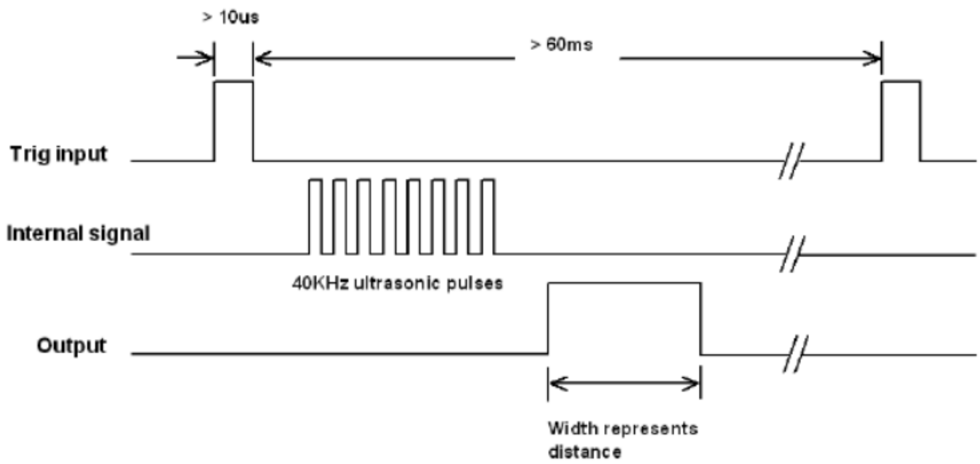


Figure II. 4: principle of operation and measurement.

To calculate the distance traveled by sound, multiply the speed of sound (about 340 m/s or 34'000 cm/1'000'000 µs) by the propagation time, giving the formula: d = v · t (distance = speed × time)

The HC-SR04 provides a pulse duration in tens of µs. Therefore, the time t is obtained by multiplying the value obtained by 10 µs. We also know that sound makes a round trip. So, the distance is half of that.

$$d = 34'000 \text{ cm}/1'000'000 \text{ µs} \cdot 10 \text{ µs} \cdot \text{value} / 2$$

Simplifying, we get

$$d = 170'000 / 1'000'000 \text{ cm} \times \text{value}.$$

Therefore:

$$d = 17/100 \text{ cm} \times \text{value}$$

The formula d = duration/58 cm is also given in the HC-SR04 user manual because the fraction 17/1000 is equal to 1/58.8235. However, this formula gives less precise results.[4]

2.1.4. Metal touch sensor:

2.1.4.1. Description:

The KY-036 Metal Touch Sensor Module is an analog/digital sensor that uses a transistor to detect changes in electrical conductivity. The digital output can be used a switch that changes state when touched. The analog output can measure the intensity of the touch. The detection threshold can be regulated using the on-board potentiometer.

Figure II. 5: metal touch sensor.

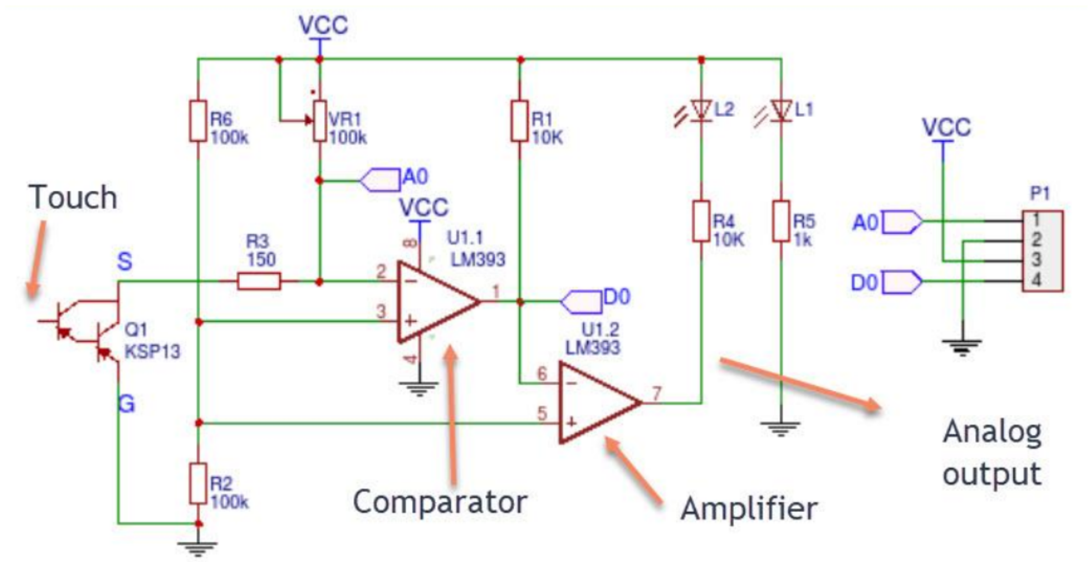


Figure II. 6: metal sensor touch sensor.

2.1.4.2. Characteristics of the detector:

This module consists of a transistor to detect touch with a power voltage of 3.3V to 5.5V, an LM393 differential comparator to control the digital output, a 3296W potentiometer to adjust the detection threshold, 6 current limiting resistors, 2 indicator LEDs and 4 male header pins.

The module features analog and digital outputs.

2.1.5. Load cell sensor:

2.1.5.1. Description:

A sensor of charge (commonly called a "load cell") is an electronic device that converts tension and compression forces into a corresponding electrical signal. Load cells are generally used to determine the weight of an object, but they are also used to quantify tension (as in cables and pulleys). Although the design and functions vary according to load cells, they all measure resistance and/or deformation inside the sensor to determine the magnitude of tension and compression forces.

The most common type of load cell is the strain gauge load cell (a device used to measure the deformation or stress of materials under load). In our case, we used a force sensor designed based on strain gauges with electrical resistance under a Wheatstone bridge configuration.

Figure II. 7: charge sensor.

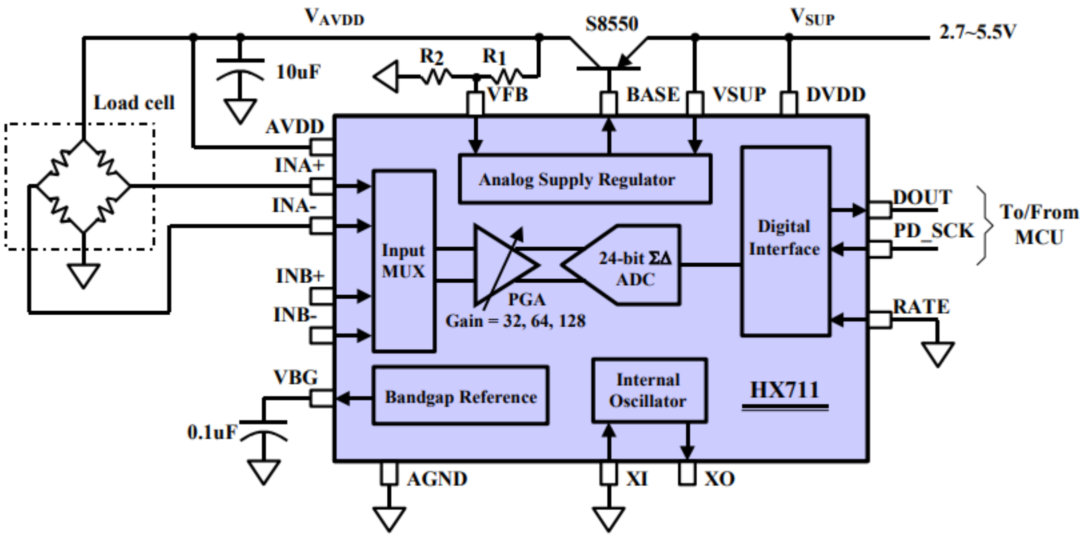


Figure II. 8: charge sensor diagram.

2.1.5.2. Electrical resistance strain gauge:

All strain gauges with electrical resistance can be considered as a certain length of conductive material, such as wires. When the wire is stretched within its elastic limit, its length increases while its diameter decreases and its resistance changes. If the conductive material is attached to the elastic strain element, the resistance change can be measured and used to calculate the force based on the calibration of the device.[6]

2.1.5.3. Operating principle:

Strain gauge-based load cells use a Wheatstone bridge circuit to amplify and decrease the power supply network. This configuration compensates for temperature effects and eliminates signals caused by external forces. A complete Wheatstone bridge circuit consists of four branches, each with at least one precision strain gauge. A stable excitation voltage of 5-20 volts is required to power the bridge.

In a simplified version of a load cell with a strain gauge using a Wheatstone bridge, all strain gauges have the same resistance value, forming a balanced bridge when there is no load. When a load is applied to the load cell, the strain gauge deforms, changing its resistance and creating an unbalanced bridge, resulting in an output voltage proportional to the applied load.

The load applied to the load cell stretches the tension gauges (T1 and T2) while compressing the pressure gauges (C1 and C2). The output voltage is then sent to the signal conditioner via signal wires (+S and -S) to convert the output voltage into force values (lb, N, kg, etc.). Factors such as temperature, wire length used to complete the circuit, and strain gauge arrangement affect resistance in the bridge, causing errors in the measured value. In precision load cells, these effects can be compensated by adding resistance to the bridge.

The easiest way to obtain a weight reading from these cells on an Arduino is to use the HX711 amplifier module. It reads the small tension change inside the load cell and converts it into a 24-bit numerical value that can be interpreted by the Arduino as a weight value.[7][8][9][10]

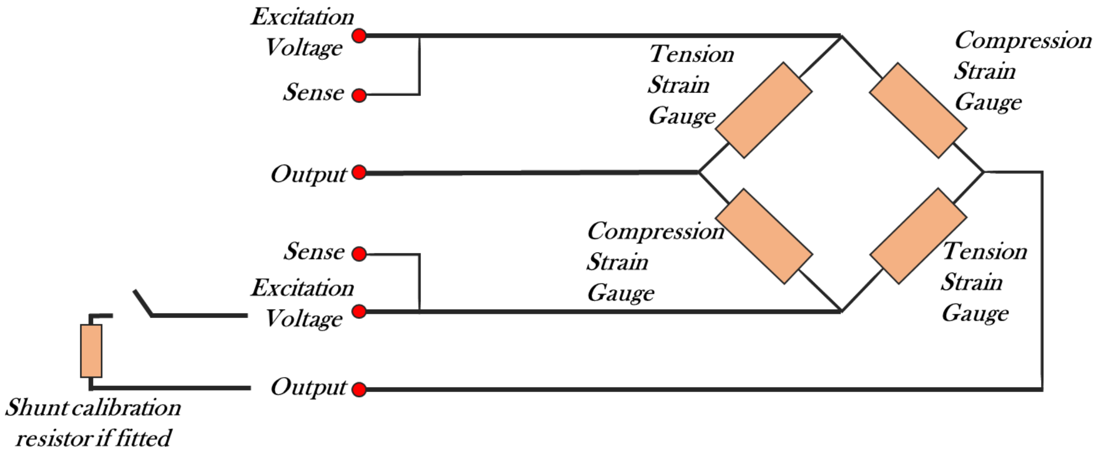


Figure II. 9: Wheatstone Bridge.

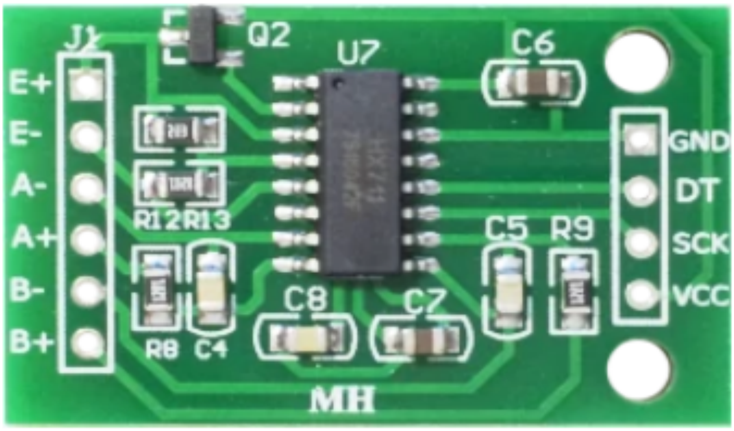


Figure II. 10: HX711 module.

2.1.5.4. Characteristics of the HX711 module:

- Supply voltage: 5V
- Current consumption: less than 10mA
- Differential input voltage: ±40mV
- A/D conversion resolution: 24 bits (16777216 counts)
- Reading frequency: 80 Hz.

2.1.6. Stepper motor:

2.1.6.1. Description:

The type of motor used is the 28-BYJ48 stepper motor, which has a unipolar configuration with four coils, each rated at +5V. These motors have a step angle of 5.625°/64, which means that a rotation is performed with 64 steps, each extending over an angle of 5.625°, providing a certain level of precision. However, these motors operate only with a supply voltage of 5V and cannot generate a high torque.

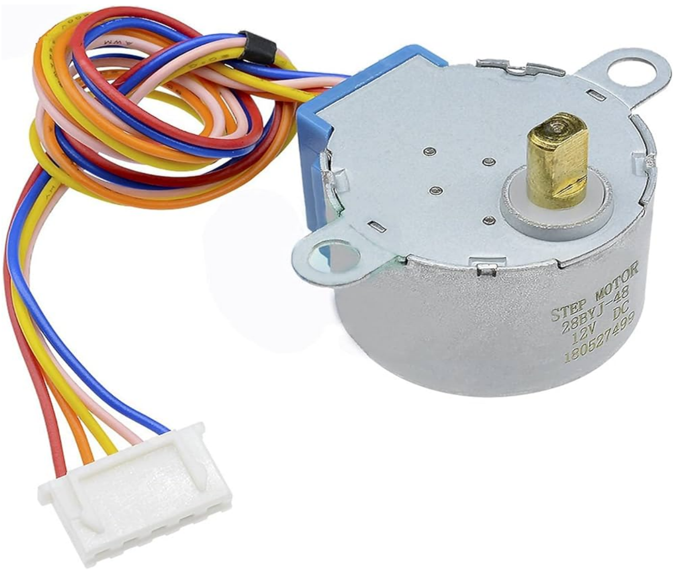


Figure II. 11: stepper motor.

To understand the operating principle of this motor, see the coil diagram below:

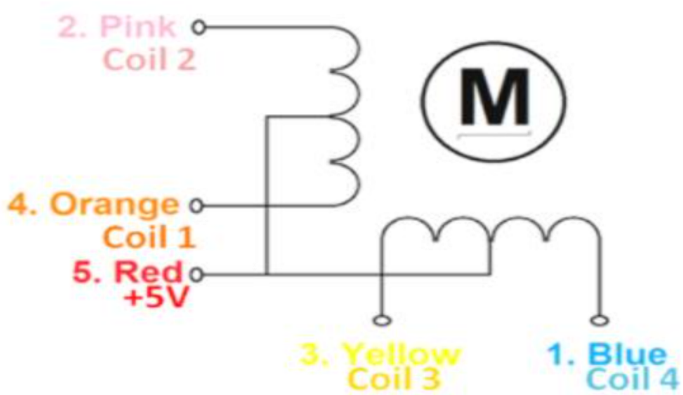


Figure II. 12: stepper motor diagram.

Given that the ULN2003 driver integrated circuit is necessary to make controlling this motor a simple task and to optimize the electrical current consumption.

The stepper motor used in this project has four coils, one of which is connected to a constant +5V power supply, while the others are output as wires. For the motor to function, it is essential that the coils are powered in a logical order. A microcontroller or digital circuit can be used to program this logical sequence. The table below shows the order in which each coil should be triggered. When the coil is held at +5V, it will not be powered, and when it is grounded, it will be energized.

	Sequence of rotation in the clockwise direction							
Color of the motor wires	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
Orang	0	0	1	1	1	1	1	0
Yellow	1	0	0	0	1	1	1	1
Pink	1	1	1	0	0	0	1	1
Blue	1	1	1	1	1	0	0	0
Red	1	1	1	1	1	1	1	1

Table II. 2: Stepper motor's sequence of rotation.

2.1.6.2. Characteristics of the 28-BYJ48 motor:

- Nominal voltage: 5 VCC
- Number of phases: 4
- Step angle: 5.625°/64
- Pulling torque: 300 gf.cm
- Isolated power supply: 600 VAC/1mA/1s
- Coil: Unipolar coil with 5 leads.

2.1.7. Driver ULN2003:

2.1.7.1. Description:

This device is useful for driving a wide range of loads, including solenoids, DC motors, LED displays, thermal print heads, and high-power buffers.

2.1.7.2. Characteristics:

- Seven Darlington transistors per package
- Output current of 500 mA per driver (600 mA peak)
- Output voltage of 50 V

- Integrated suppression diodes for inductive loads
- Outputs can be paralleled for higher current
- TTL/CMOS/PMOS/DTL compatible inputs
- Input pins placed opposite to output pins to simplify layout. [11]

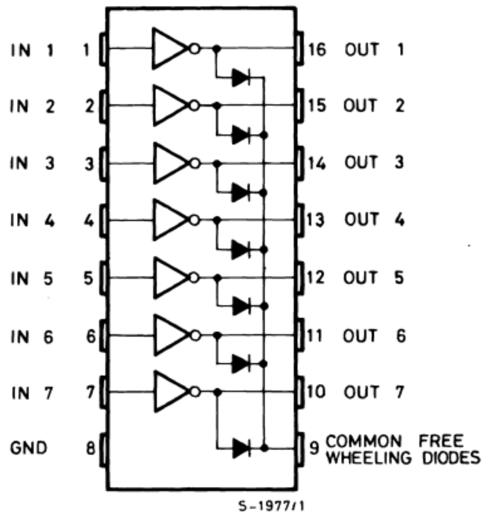


Figure II. 13: ULN2003 diagram.

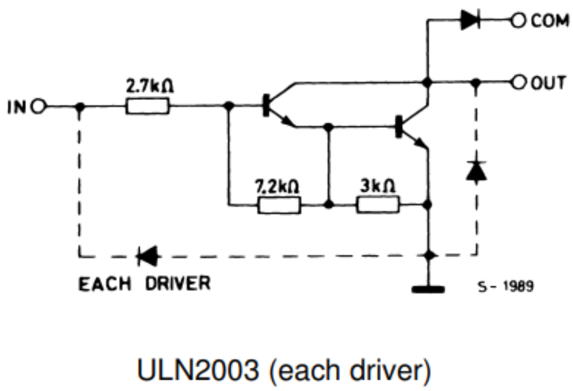


Figure II. 14: ULN2003 each driver.

2.1.8. LCD display:

2.1.8.1. Description:

LCD stands for Liquid Crystal Display, a type of electronic display module widely used in various applications like mobile phones, calculators, computers, TVs, and more. These screens are commonly chosen for their multi-segment and seven-segment LED displays. The key benefits of using LCD modules include cost-effectiveness, easy programmable animations, and the ability to display custom characters, special animations, and more without limitations.

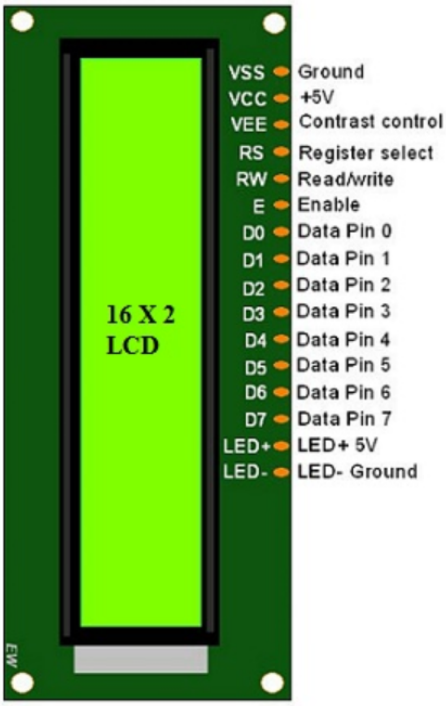


Figure II. 15: LCD 16×2 pinout.

2.1.8.2. Characteristics of an LCD:

Feature	**Description**
Display type	Alphanumeric LCD
Display size	16 characters per line, 2 lines
Custom characters	Supports 8 custom characters (numbered 0 to 7) of 5×8 pixels each
Power supply	Typically powered by +5V
Communication	Can be connected directly or via an I2C module with Arduino Uno, Nano, or Mega

Table II. 3: Characteristics of an LCD.

2.2. Software section:

In this section, we will provide a brief overview of the three software applications utilized in this project.

2.2.1. Arduino IDE:

2.2.1.1. Description:

The Arduino IDE is an open-source and free software used to program electronic boards, including those that are not Arduino. It allows programming in block or line code format, using a specific programming language for Arduino. The Arduino IDE has a compiler that converts the program into machine language understandable by the board. It also allows uploading the program to the board's memory via the computer's USB port. The Arduino IDE is a user-friendly graphical interface that includes all the necessary tools for programming for Arduino, including a debugger to correct errors in the program. It is available for download on the official Arduino website.

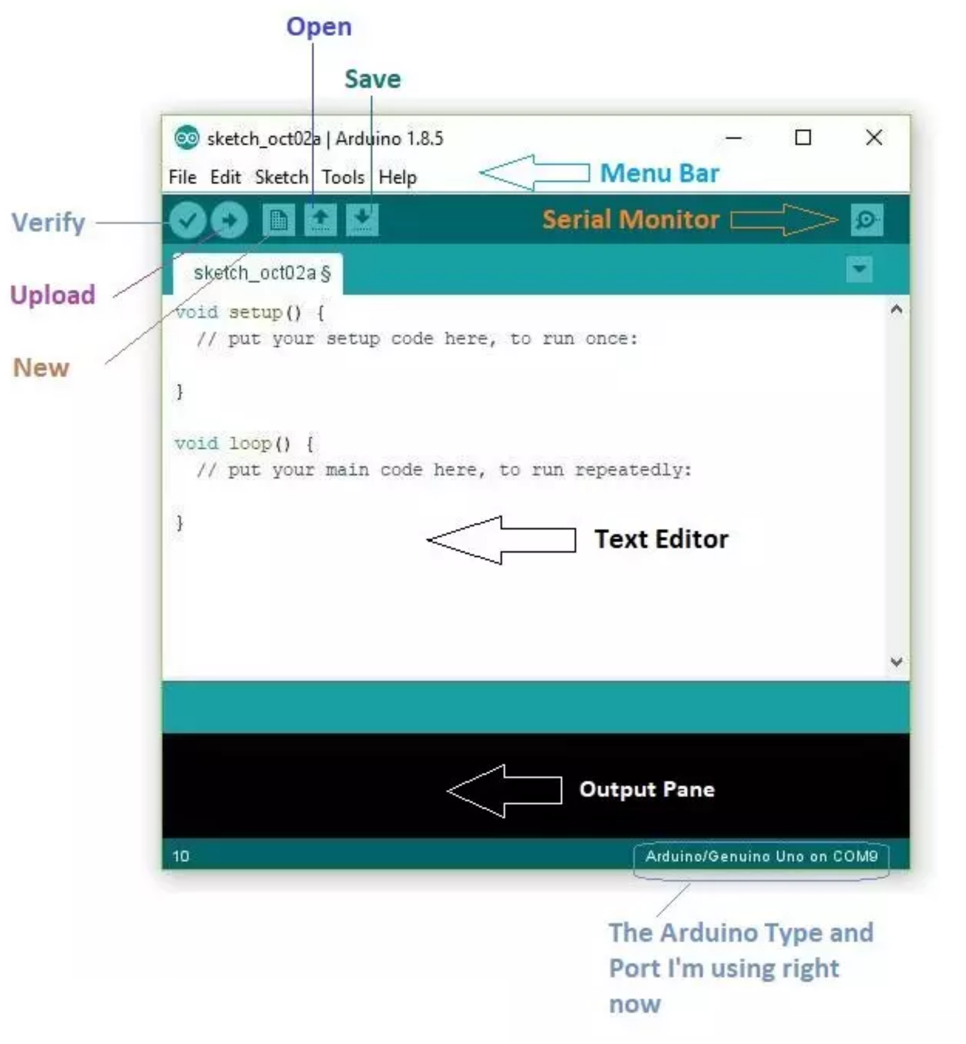


Figure II. 16: Arduino IDE interface.

2.2.2. SolidWorks:

2.2.2.1. Description:

SolidWorks is a computer-aided design (CAD) software developed by Dassault Systems. It uses the principle of parametric design, which means that 3D models are created using parameters and constraints that define their shape and function. SolidWorks can generate linked files of parts, assemblies, and drawings, which means that any modification made to one of these files is reflected in the other two. SolidWorks is known for its ease of use and intuitive interface, and it supports a wide variety of 3D file formats. It is used in a wide range of industries for product design and 2D and 3D modeling. SolidWorks also offers add-ons such as SolidWorks Simulation for stress and deformation analysis, SolidWorks Flow Simulation for fluid flow simulation, and SolidWorks Motion for mechanical system dynamics simulation.

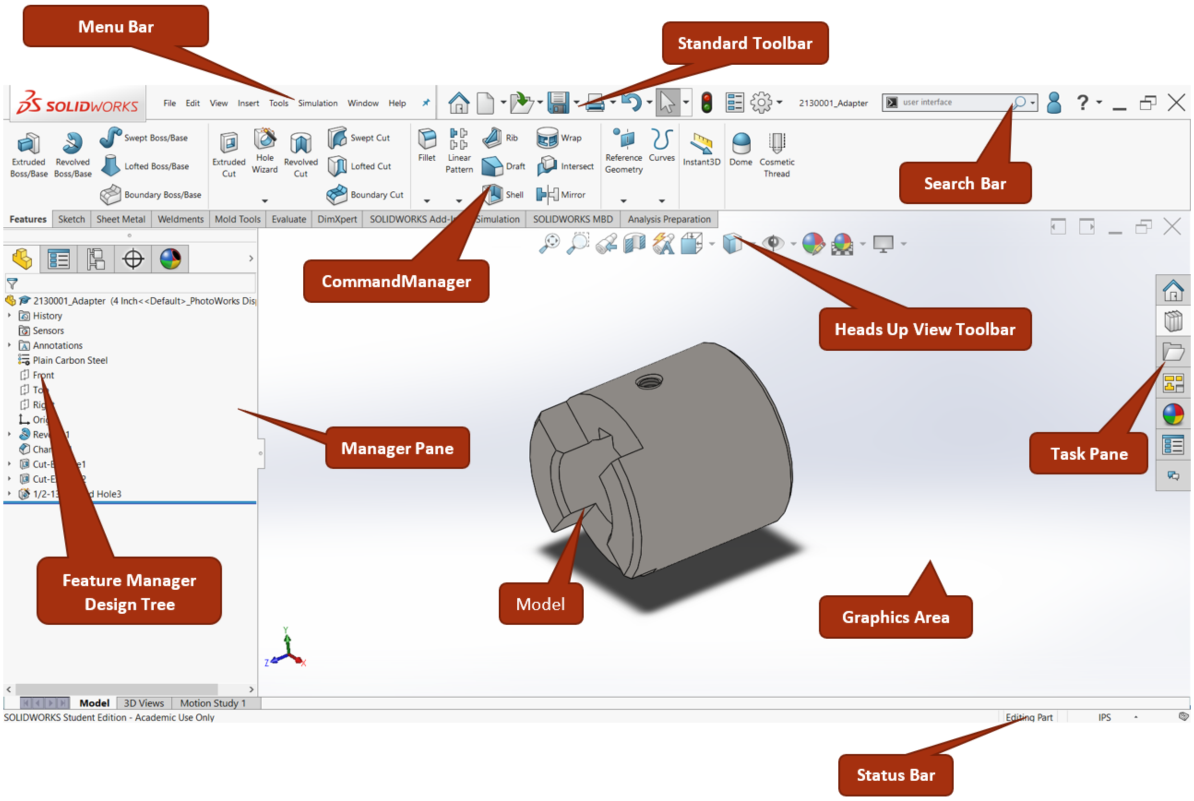


Figure II. 17: Solidworks interface.

2.2.3. Proteus Professional:

2.2.3.1. Description:

Proteus Professional is a CAE (Computer-Aided Engineering) software used in the electronics industry. It includes several modules, including ISIS, ARES, PROSPICE, and VSM, all of which are dedicated to electronics. ISIS is primarily used for editing electrical schematics and simulating circuits, while ARES is a tool for editing and routing printed circuit board designs. The software allows for the creation of structural schematics and their simulation, which helps detect certain errors during the design phase. It is used in many companies and training institutions, including high schools and universities. The software is known for its ease of use and excellent technical support, as well as its virtual prototype creation tool, which helps reduce material and software costs during project design.

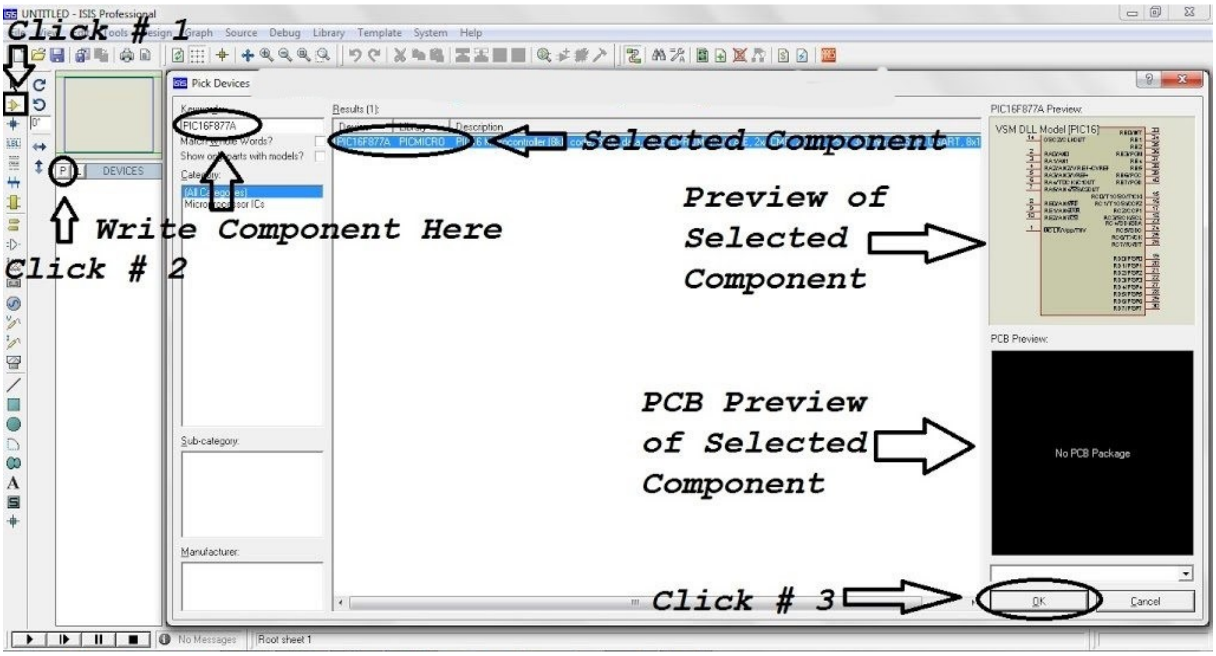


Figure II. 18: Proteus interface.

3. Conclusion :

This chapter has presented a comprehensive overview of the various resources used for the design of an intelligent recycling machine, combining hardware and software resources. We started with the Arduino UNO board, which is the heart of the system, then used advanced sensors to make the machine intelligent. We also used a stepper motor to ensure the operation of the machine. Finally, we used software resources to design the control circuits, program them, and establish the design of the machine itself. These software resources include design and simulation tools, as well as programming languages to program sensors and motors. By combining these resources, we were able to create an intelligent recycling machine capable of accurately and efficiently detecting and sorting recyclable materials.

Chapter Three:
Intelligent Recycling Machine Prototype

1. Introduction:

In this chapter, we will highlight the key steps of our project titled "Design of an Intelligent Recycling Machine". We will detail the various phases of the product's development, emphasizing its positive impact on both society and the environment. We will begin by explaining the machine's recycling function, followed by the integration of electronic, mechanical, and software components described in the previous chapter. Finally, we will discuss the challenges encountered and potential improvement paths for this ambitious project.

1. Operating principle of the machine:

The operation of this intelligent recycling machine relies on the use of cutting-edge sensors and innovative techniques to optimize waste management. You will find below a flowchart detailing the operating principle and the different stages of waste sorting, ensuring an efficient and eco-friendly approach.

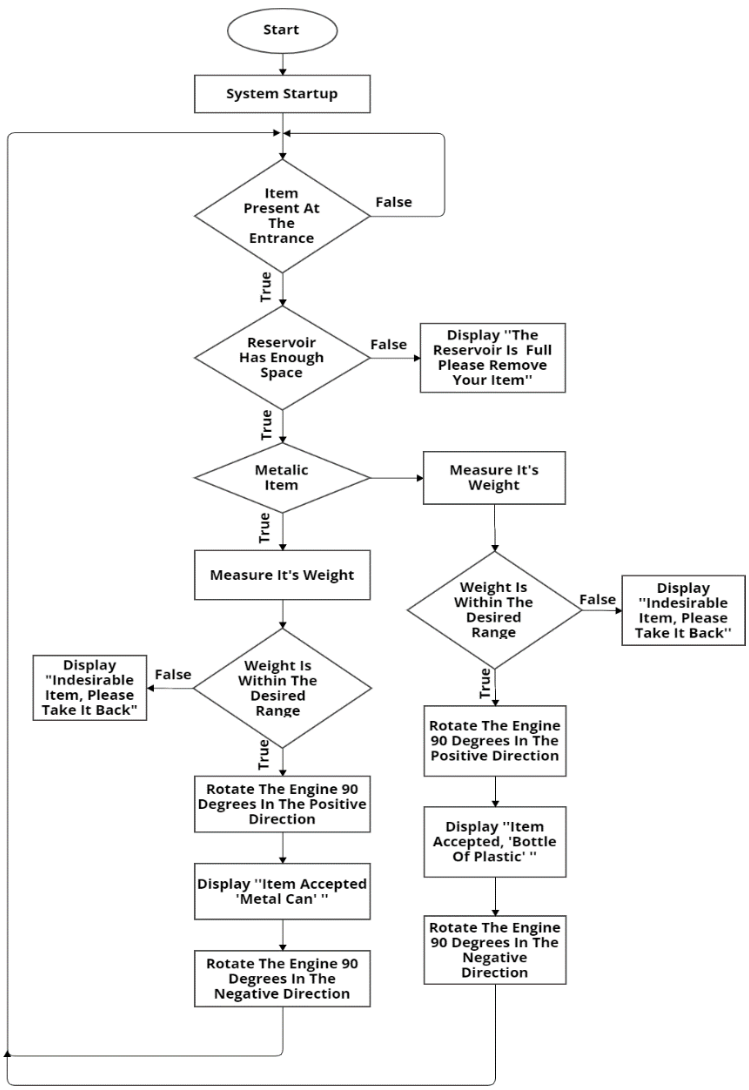


Figure III. 1: an organizational chart illustrating the operating principle.

2. Practical Implementation of Our Project:

The practical realization of our ambitious project involves controlling a smart trash can using the Arduino UNO board. This board will enable us to connect all the components mentioned in the previous chapter to create an autonomous and intelligent system capable of sorting waste optimally. In the following sections, we will detail each key step of this project, from wiring and testing each electronic component to the final assembly of all these elements and their placement on the prototype template.

2.1. Wiring the Ultrasonic Sensor:

In this setup, the ultrasonic sensor will be positioned at the entrance of the smart trash can. The ultrasonic sensor will detect the presence of an object, while the buzzer will audibly signal this detection.

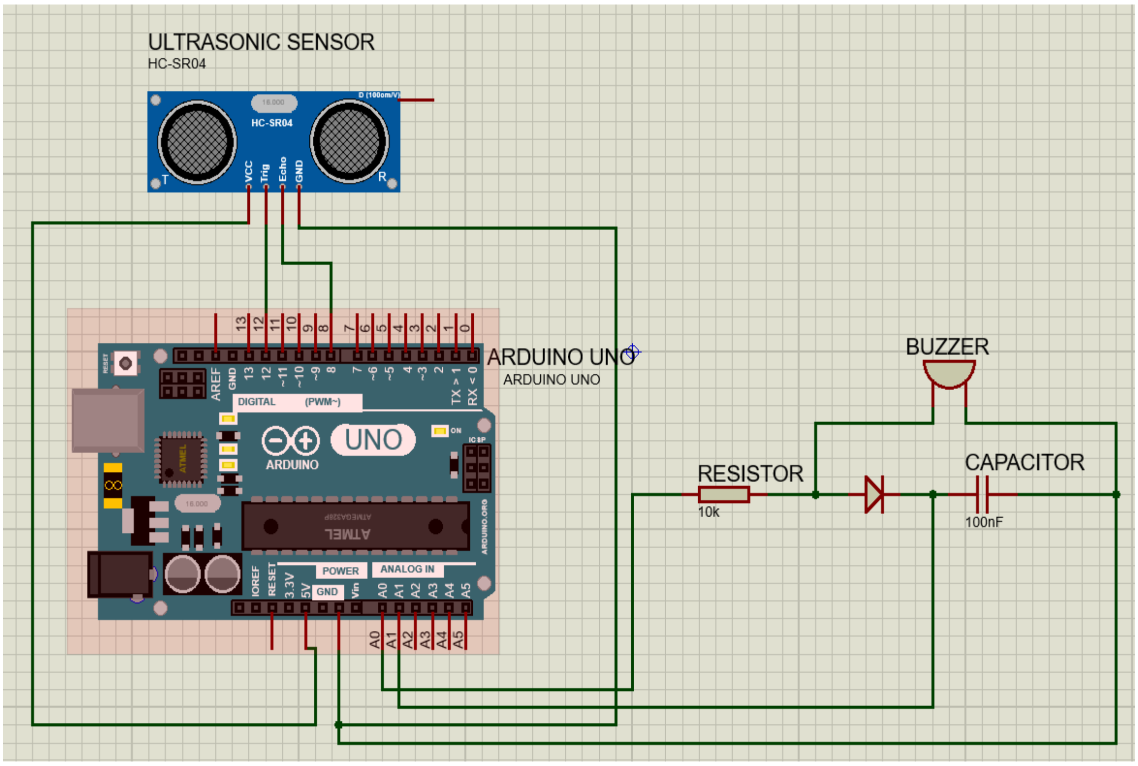


Figure III. 2: ultrasonic sensor and buzzer wiring.

In addition, we will use two more ultrasonic sensors to determine the fill level of the containers. Their wiring will be as follows:

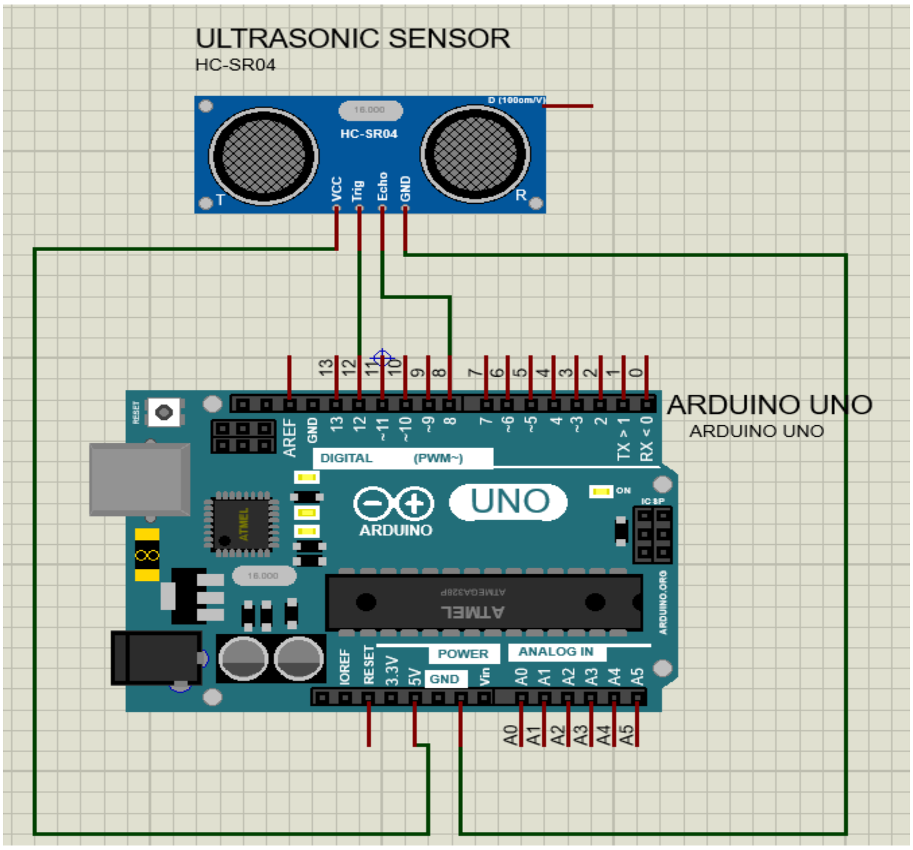


Figure III. 3: ultrasonic sensor wiring.

2.2. Wiring the Proximity Metal Detector:

The figure below illustrates how the proximity metal detector is wired. After detecting an object at the entrance of the smart trash can, it will determine if the object is an aluminum can.

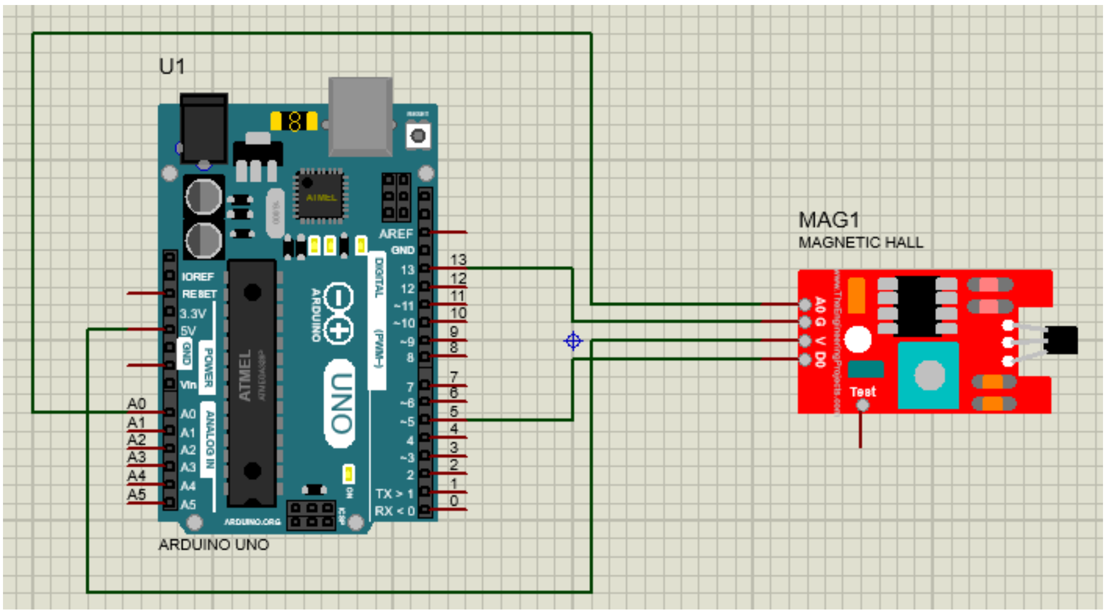


Figure III. 4: metal touch sensor wiring.

2.3. Wiring the load cell sensor:

We have chosen to integrate a load cell in this project to avoid unwanted waste. How does it work? The load cell will help us determine the weight of each object, on one hand, and the information about the weight of non-metallic objects will be very useful in determining whether it is indeed a plastic bottle or not, knowing in advance the weight range of different empty plastic bottles. Similarly for metal cans, a comparison between the weight of the weighed objects and the already known weights will allow us to determine if it is an object other than plastic or metal or even a filled plastic bottle or metal can, which will also be considered as unwanted objects.

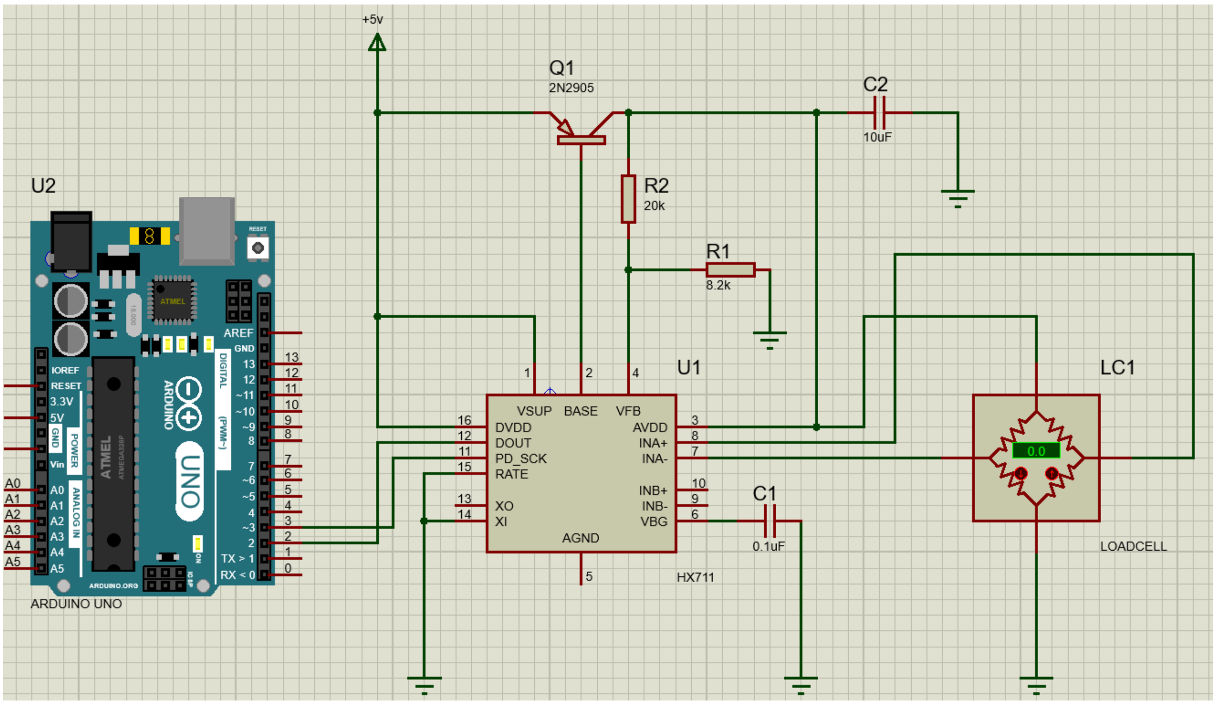


Figure III. 5: load cell sensor wiring.

2.4. Wiring the Stepper Motor:

The figure opposite shows the connection between the stepper motor, its ULN2003A driver, and the Arduino Uno. The stepper motor will allow us to rotate the container, divided into two parts, in a specific direction and degree, so that plastic bottles are stored in their dedicated compartment, and metal cans in theirs.

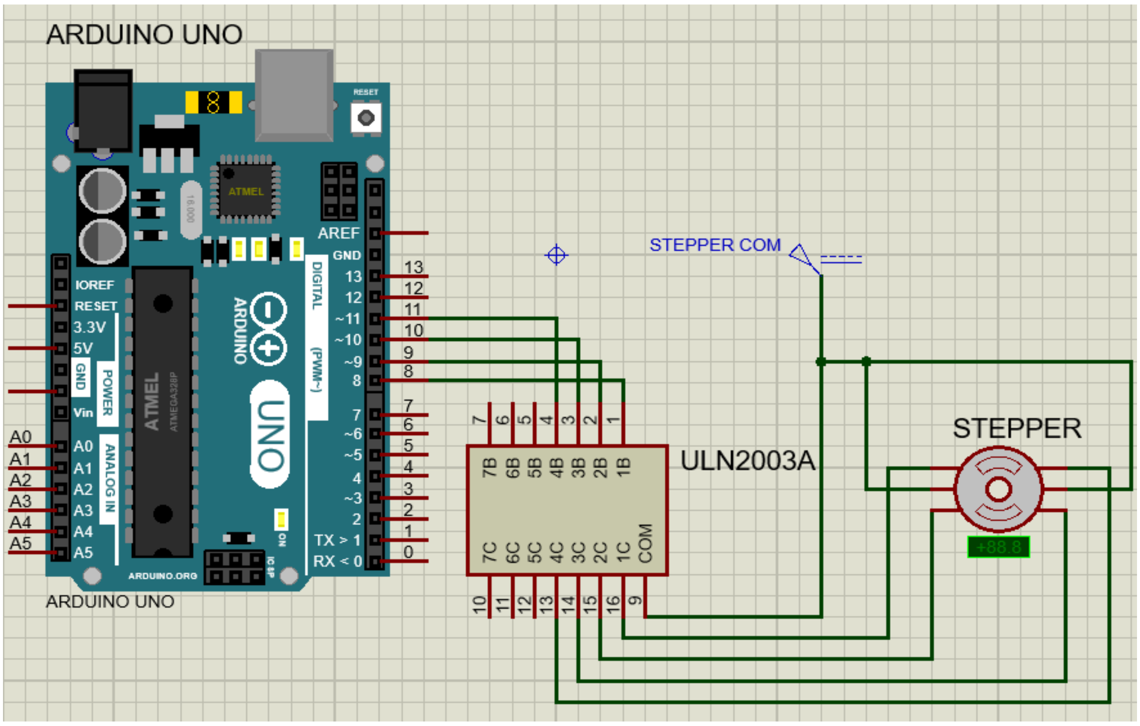


Figure III. 6: stepper motor wiring.

2.5. Wiring the LCD Display:

For this project, we have chosen to use an external 16×2 LCD display, which allows us to display messages to users, such as "your object is accepted", "your object is rejected", "undesirable object, please remove it", and even "the container is full, please remove your object".

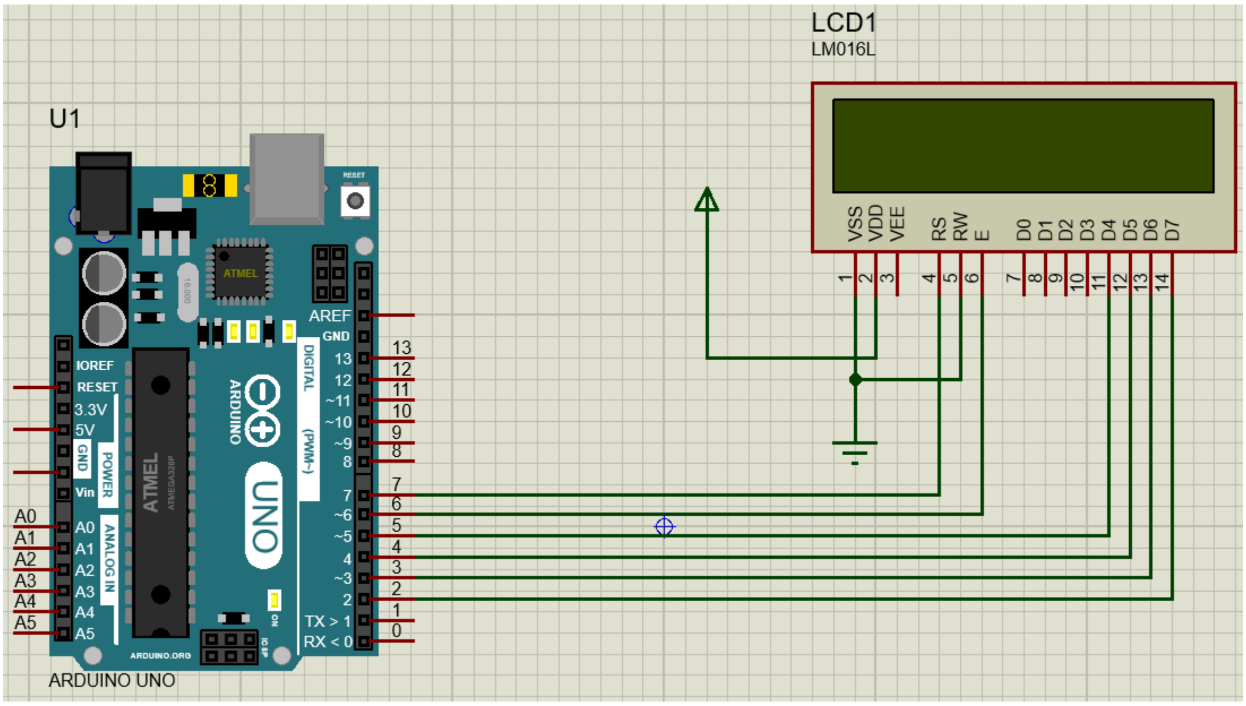


Figure III. 7: LCD display 16×2 wiring.

2.6. General assembly:

Now that we have detailed each component used in this project, we can proceed to the final assembly of the control section of our intelligent recycling machine. Notably, we will be utilizing the Arduino MEGA board, which offers a significant advantage due to its large number of pins, allowing us to connect all the components seamlessly.

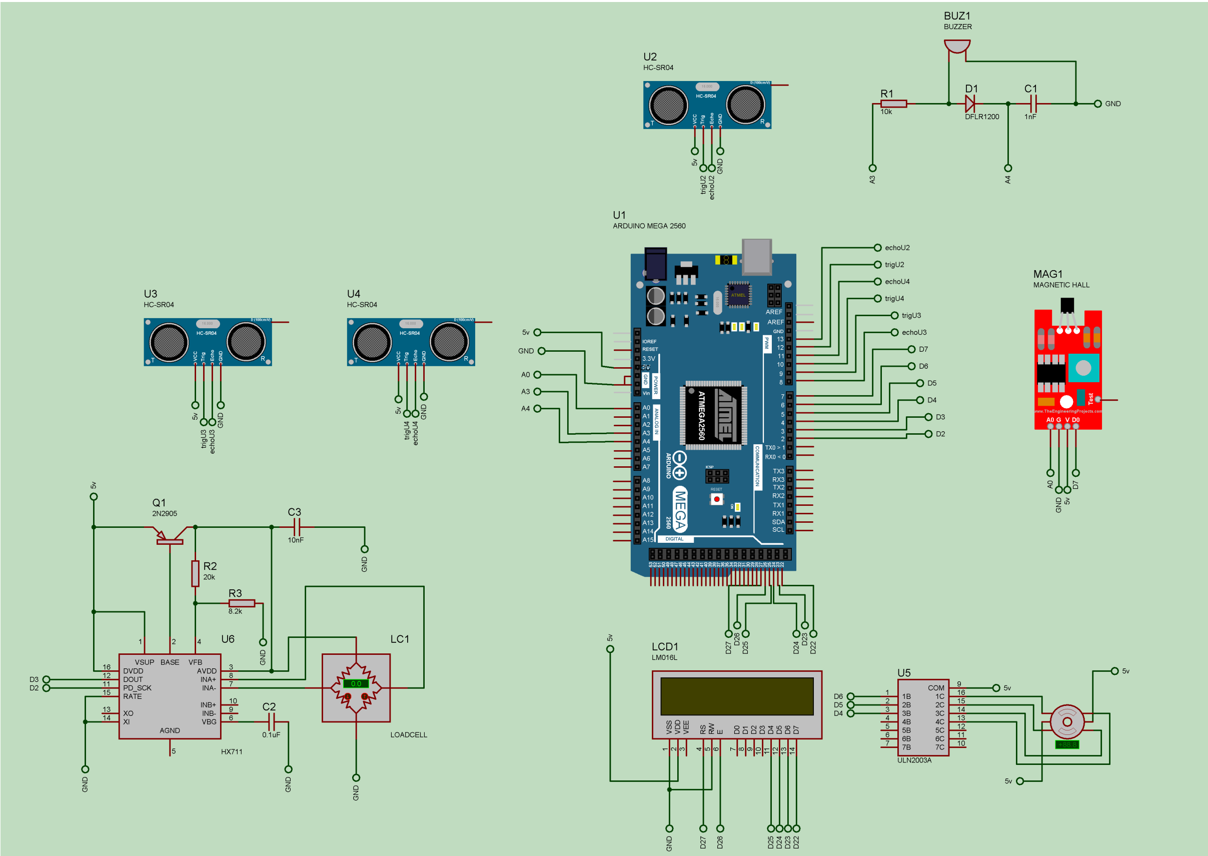


Figure III. 8: General assembly

3. Designing the Machine Body

For this machine to be fully functional, it requires a body that enables it to effectively perform the task for which it is designed. This involves integrating the control unit described earlier with a detailed design process and practical implementation of the body.

To design this smart trash can, we used the computer-Aided Design (CAD) software SolidWorks. The following images will provide a glimpse of what our recycling machine will look like.

The figure below depicts the overall body of the smart trash can, showcasing the entry point where waste is deposited and detected.

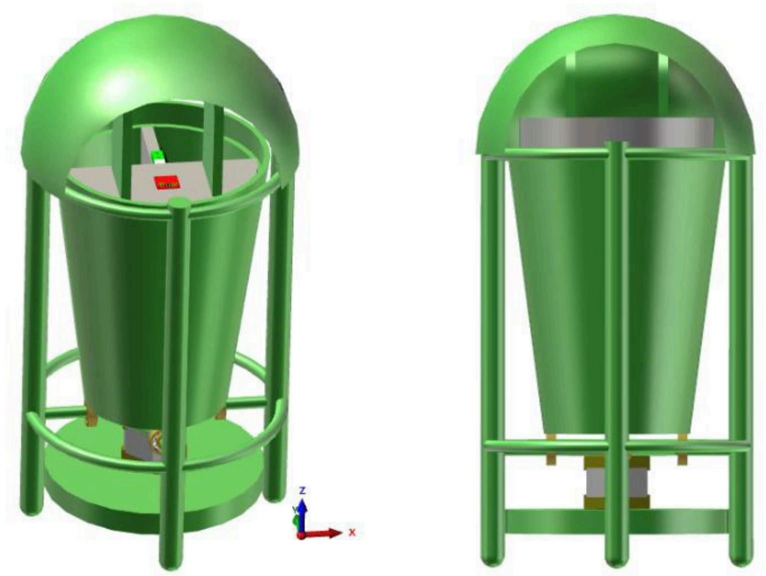


Figure III. 9: the overall body of the recycling machine.

The following figure illustrates the placement of the essential electronic components for waste sorting. The bearings shown below are implemented to facilitate the manipulation of the mobile part of the smart trash can, enabling the mechanism to isolate each object in its appropriate reservoir.

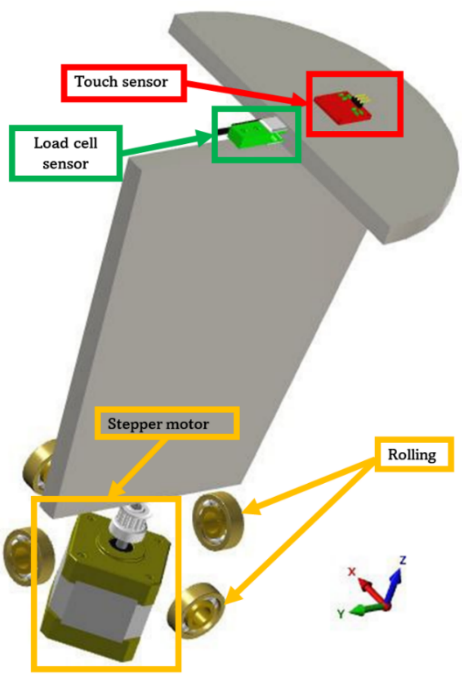
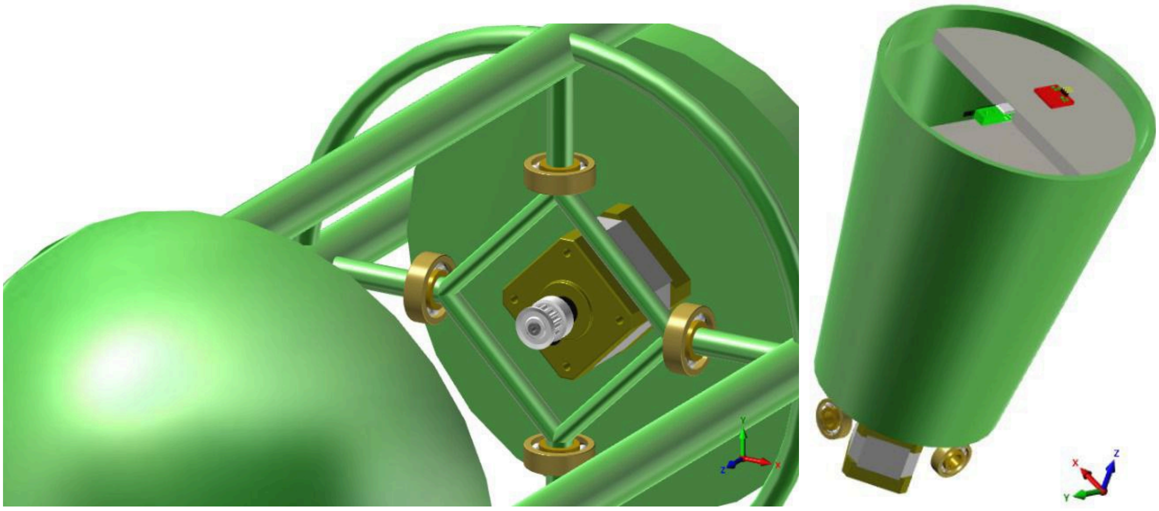


Figure III. 10: figure showing the inside of the machine and the emplacement of essential electronic components.



(a) (b)

Figure III. 11: (a) Stepper motor's fixation, (b) Mobile part of the recycling machine.

The following figures showcase the machine from various angles, providing a more detailed view of the entire smart trash can.

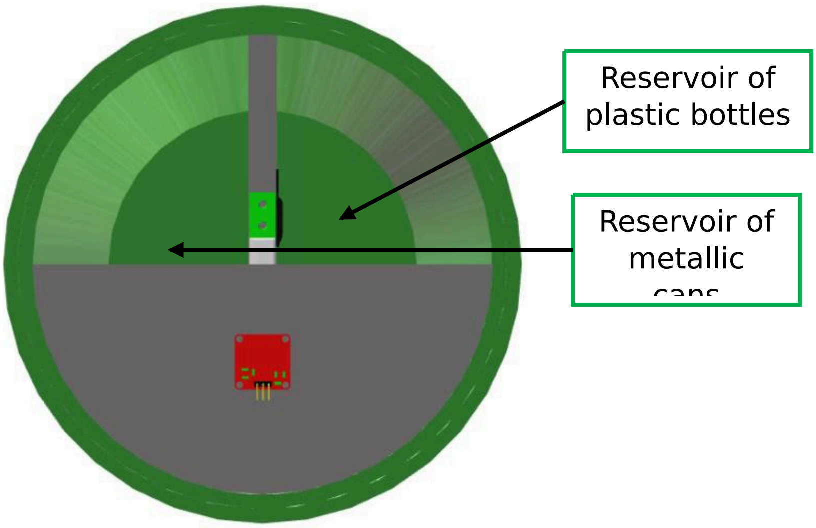


Figure III. 12: figure showing the reservoir of each plastic bottle and metallic cans.

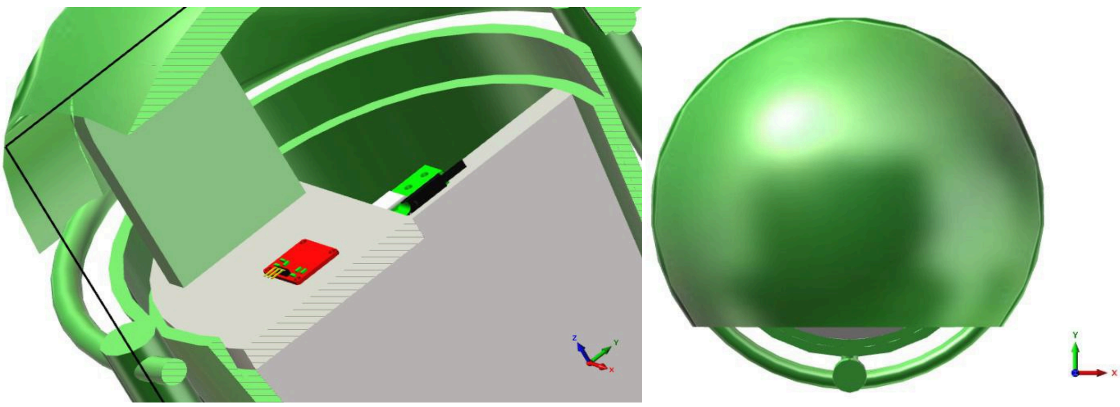


Figure III. 13: (a) Longitudinal section of the recycling machine, (b) Recycling machine from above.

Here are some actual images of the final machine body as well as the wiring of the electronic components giving this machine an intelligent and innovative look.

Figure III. 14: photo showing the inside of the machine.

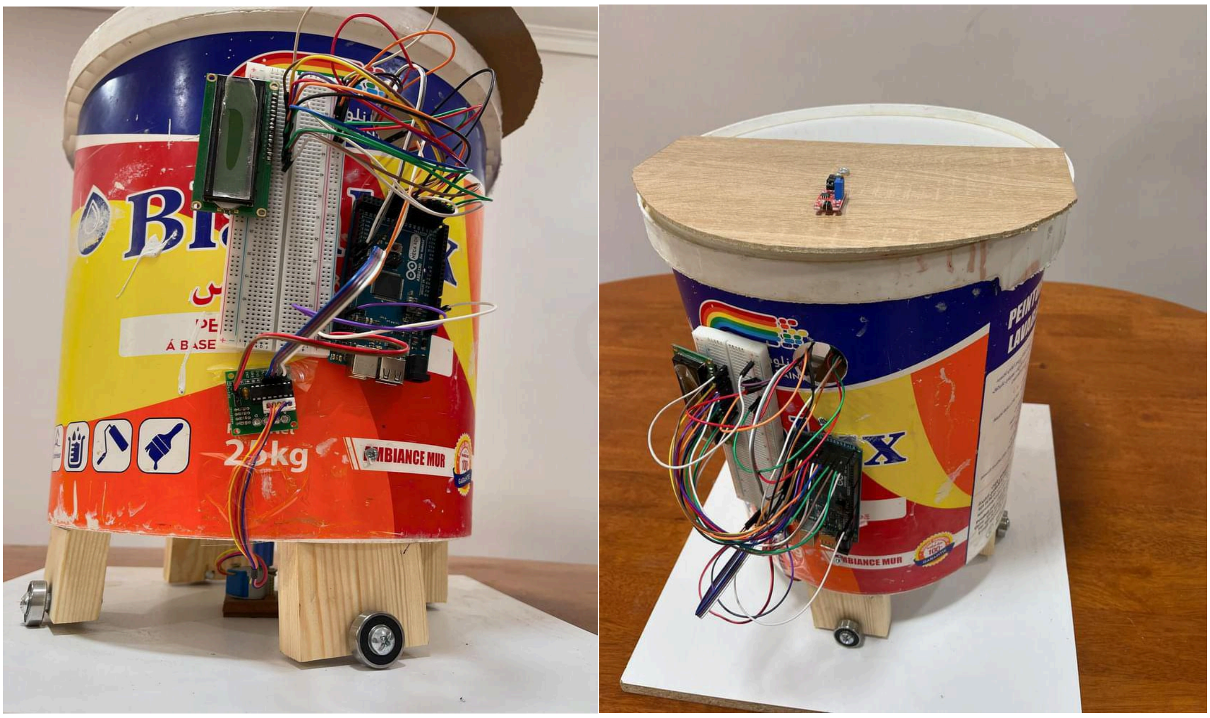


Figure III. 15: photo showing the assembly of electronic components.

To simplify the assembly process and reduce the complexity, we have chosen to use a PCB (Printed Circuit Board). This allows us to directly connect each component to its dedicated pins on the board, minimizing the need for connecting wires. By eliminating the use of numerous wires, we can significantly reduce the chances of wiring errors and create a more organized and reliable circuit.

The PCB provides a clean and efficient way to establish the necessary connections between the components and the Arduino pins. This approach not only makes the assembly process more straightforward but also enhances the overall reliability and robustness of the circuit.

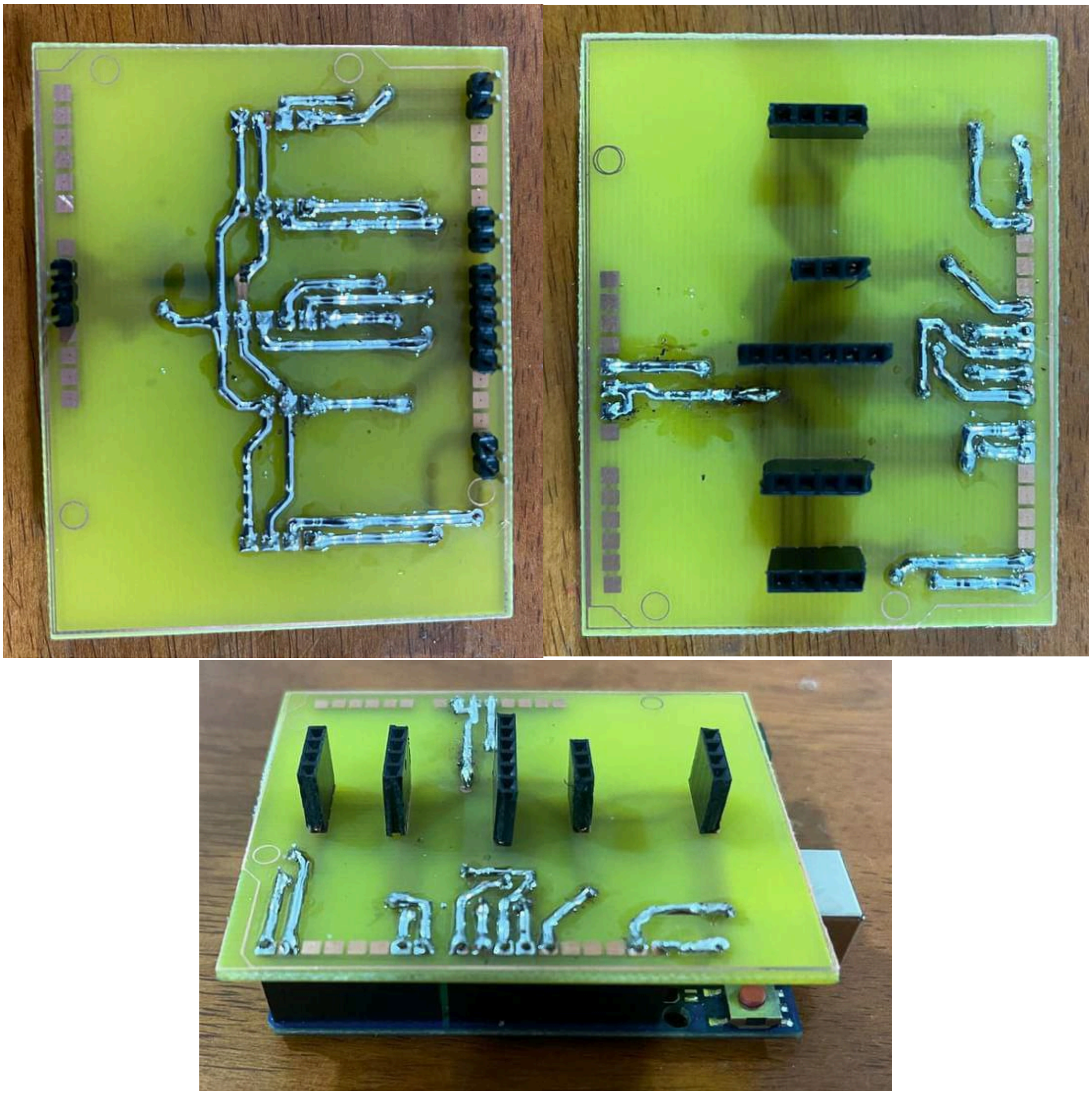


Figure III. 16: Printed Circuit Board.

Figure III. 17: figure showing the outside of the machine.

4. Possible improvements:

The smart trash can we have just realized is certainly innovative and based on a simple and effective principle, serving both society and the environment. However, it can still undergo further improvements to make it more efficient and, above all, more autonomous. Among these improvements, we can mention:

- Creating a platform that connects all the trash cans to the same server, allowing for remote monitoring of their status and fill level without the need for manual verification.
- Adding a crusher at the level of each reservoir to increase the storage capacity for waste.
- Integrating other methods and techniques for efficient waste sorting, such as recognition techniques based on artificial intelligence.
- Creating a platform that allows people in society to create personal accounts where they can save the amount of waste they have put into these smart trash cans and be rewarded later to encourage them to collect and dispose of their waste more frequently.

5. Conclusion:

This chapter provided a general overview of the steps taken for the design and implementation of our project. We discussed the overall operation of the machine, and presented the electrical schematics created for each electronic component separately, as well as the overall electrical schematic of the control section of the smart trash can. Furthermore, we delved into the design of the machine using Computer-Aided Design (CAD) software SolidWorks and the implementation of this design in the real world by manufacturing the body of the machine. This primary version of the project will benefit from a series of improvements, which was the final point discussed in this chapter before concluding.

General conclusion:

This master's dissertation on the design of an intelligent recycling machine has allowed us to explore various aspects related to the sustainable and efficient management of waste. Through the three chapters of this dissertation, we have addressed the generalities on different types of waste and their treatment methods, the study of the various electronic and software components used, and finally the realization of a prototype.

The first chapter was an introduction to the different types of waste caused mainly by rapid population growth and urbanization, the current methods for managing all this waste, and how we can create and develop innovative approaches to collect, sort, and treat it efficiently and autonomously.

The second chapter of this thesis spoke in detail about the various resources we were able to use, whether material or software. We were able to evaluate different solutions and explore the possibilities of creating an intelligent recycling machine capable of making the waste collection process optimal and efficient.

Finally, in the third chapter, we concretized our study by creating a prototype of the intelligent recycling machine. This prototype allowed us to test our concepts and draw lessons from the practical aspects and potential improvements to be made to our solution.

In conclusion, this master's dissertation has highlighted the importance of developing ecological and intelligent solutions to meet the challenges of waste management. Technological advances offer promising opportunities to optimize the collection, sorting, and treatment of waste while reducing their impact on the environment. However, there are still challenges to be met, such as social acceptance, regulatory constraints, and necessary investments.

We hope that this study will serve as a basis for future research and development in the field of waste management. By adopting a holistic approach, including awareness, education, and stakeholder involvement, we can work together towards more sustainable waste management, thus contributing to the preservation of our environment and the construction of a better future for generations to come.

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