AUTOMATED WASTE SEGREGATOR WITH SENSOR-BASED DETECTION FOR ENHANCED WASTE DISPOSAL

A mini–Research Project

In Partial fulfillment of the Requirements for the course

ENS 341 Research Methods for Engineering

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CHAPTER I

INTRODUCTION

1.1 Background of the Study

The rapid increase in global waste generation, driven by urbanization, industrial growth, and rising population, presents serious environmental and logistical challenges. This has become one of the major problems, as waste is not properly segregated because people often just throw their trash anywhere without sorting it. Proper waste segregation is not easy, especially when the volume of waste is large and mixed. The traditional waste management system often relies on manual waste segregation, which leads to increased landfill dependency, resource loss, and pollution. The problem will only get worse for both the environment and people's health. It is important to find better and more effective ways to handle and manage waste.

This study proposes automated waste segregation with the combination of sensor-based detection and machine techniques to identify and separate waste into proper categories. Sensor-based detection and machine learning techniques will be utilized to classify and separate waste into appropriate categories such as biodegradable, non-biodegradable, and recyclable materials. This research aims to support more effective waste disposal strategies and promote sustainable waste management practices. This reduces the need for human labor and improves the overall reliability of the process. Using smart technology for waste sorting is a major step toward cleaner, safer, and more sustainable waste management and also an essential move toward a more circular economy, where materials are reused and recycled efficiently. To contribute long-term environmental sustainability and serve as a foundation for future innovations in automated waste management.

Furthermore, integrating automation into separating waste is consistent with the global movement towards green technologies and smart cities. The need for clever ways to preserve environmental balance grows as metropolitan centers continue to grow. In addition to addressing present waste management constraints, automated technologies open the door for future infrastructures that are flexible and scalable. Waste can be sorted more precisely and reliably with the aid of sensors and AI-driven algorithms, which lowers contamination rates and increases recycling effectiveness. This program promotes responsible consumer behavior, raises educational awareness, and gives communities the tools they need to engage in more environmentally friendly activities.

1.2 Statement of the Problem

Due to the rapid increase of global waste generation, driven by urbanization, industrial growth, and around environmental sustainability, has led to serious environmental and waste management issues. The improper waste segregation continues to be a significant problem as many individuals throw their trash without segregating into proper waste disposal. Many communities will depend on manual sorting:

1. Inefficient since they fail to handle the high and increasing amount of daily waste;
2. Labor-intensive in that it takes a lot of human energy and time;
3. Error-prone, which mostly results in contamination of recyclable waste and lowers the overall efficiency of recycling; and
4. Toxic, subjecting workers to unhygienic and possibly harmful substances. With trash nowadays made up of a big mix of materials biodegradable, non-biodegradable, recyclable, and toxic the task of proper segregation has become even more complicated.

To solve all these problems, this research aims to solve the following major problems:

1. How can automated systems sort and categorize waste properly into biodegradable, non-biodegradable, and recyclable categories?
2. How can sensor technology and machine learning be combined to enhance the speed and accuracy of the segregation process?
3. How can automation minimize human involvement and thereby reduce health hazards and labor needs?
4. How can the proposed system ensure sustainable and efficient waste management practices?

By responding to these queries, this study hopes to provide a practical and innovative solution to contemporary waste segregation through the use of smart technologies.

1.3 Objectives

This study aims to develop an automated waste segregator with sensor-based detection for enhanced waste disposal that can make sure that the waste is properly segregated and innovate a more accurate waste disposal. The following are the objectives of the study:

1. To design a waste segregation system that will sort and categorize biodegradable, non-biodegradable, and recyclable accurately.
2. To integrate sensor technology with machine learning for the improvement of speed and accuracy of waste segregation.
3. To reduce human involvement that can reduce health risks and lessen manual labor through automated systems.
4. To implement sustainable and efficient waste management that will help promote environmental responsibilities through smart automation.

1.4 Significance of the Study

This research, automated waste segregation provides a contribution to the society by promoting efficient and safety waste disposal management, this will help to avoid pollution to the environment. The researchers believe this project will be beneficial and relevant to the following:

Environmental Agencies and Advocates. This research will promote a clean and safe environment. It will help them assure the people around the world to have a healthy lifestyle.

Local Government Units and Waste Management Services. Automated waste segregation helps workers to have an easier life it will make less of people's manual labor. This will also help in proper segregation without any effort of the workers in the municipality.

The Public and Community. As we can see, the most common problem today is improper waste segregation. People tend to throw their waste whatever type of trash they throw, even though their trash is not in the right trash bin. This research will help to have a more innovative and easy waste segregation.

Academy and Educational Institutions. This research can be a big help to institutions in demonstrating to their students how to have an easy and accessible automated waste segregation.

Future Researchers. This study will provide researchers with ideas on how to properly segregate waste without manual labor. This can be a recommendation to those researchers who want to study automated waste segregation.

1.4 Scope and Limitations

This study focuses on the design, development, and evaluation of a functional, small-scale automated waste segregation prototype capable of categorizing waste into biodegradable, non-biodegradable, and recyclable materials. The system integrates sensor-based technologies to detect and classify waste based on measurable physical properties such as weight, composition, and material type. The objective is to enhance the efficiency, safety, and accuracy of waste disposal while promoting sustainable and hygienic waste management practices. The study is limited to the most commonly generated household and municipal waste types, such as organic matter, plastic, metal, and paper. Hazardous, electronic, and medical wastes are excluded due to the complexity and safety requirements involved in handling these materials. Even though our prototype may look amazing and work perfectly, as we test the prototype, there are some limitations that we face. For example, when we tested the waste for recyclable types, it wasn't classified as a recyclable type, but instead it was in the non-biodegradable and biodegradable types. And this is due to the fact that our inductive proximity sensor doesn't work properly. There are also times that other waste for non-biodegradable was in the biodegradable, and also some biodegradable was in the non-biodegradable. So, our prototype doesn't work that perfectly, but even though it doesn't work properly, we can still improve it in the future.

As a small-scale model prototype for research purposes, it may require further optimization for large-scale use. The system is also configured and limited to predefined waste categories and may not classify mixed-material items accurately.

CHAPTER II

REVIEW OF RELATED LITERATURE

The review of related literature for this study focuses on discussing the different parts of the research title that are to be studied based on sources. It also has related studies that help in suggesting solutions to future problems related to automated waste segregation.

2.1 Related Literature

Waste Segregation

We require a stable and sustainable development strategy because of the world's ongoing urbanization and growth. Proper waste management is a crucial component of the urban development plan. The collection of garbage is a complex operation that requires effective system management from the collection of waste to its hygienic disposal. Segregation of collected debris is crucial because if all waste materials including e-waste, old furniture, and polythene bags end up mixed up in landfills, it may cause harmful compounds to leak and contaminate the soil. Compost or methane gas are produced from the wet waste component. Biogas can be utilized as an energy source, and compost can take the place of artificial fertilizers. Paper, plastic, and metal waste can all be recycled or repurposed. The most fundamental prerequisite for initiating a management process is an automated waste segregation procedure. Therefore, we have compared several automated waste segregation systems that were put into place using diverse technologies in this research (Gangwani, 2021).

In solid waste management, segregation at the source is crucial, particularly when financial resources are scarce. Solid trash is separated into three categories: hazardous, dry, and wet. Generators are responsible for sorting waste into these three categories in accordance with the Solid Waste Management Rule of 2016. Achieving the right results is hampered by a number of factors, including a lack of awareness and the lax application of the law. We can select Reduce, Reuse, and Recycle for the proper solid wastes after segregation. Both ecologically and financially, solid waste management should be sustainable. An efficient and sound management plan is crucial in a developing nation like India. In addition to poverty, we also face a high pace of urbanization, population expansion, and inadequate funding for solid waste management techniques (Pandey, 2019).

Smart Waste Management

Waste in all its forms solid, gaseous, and liquid increases globally as a result of urbanization, industrialization, and population growth. Reuse, recycling, trash reduction, and other tactics to counteract the impact of waste generation brought on by population growth and industrialization are all part of waste management. One of the most important aspects of waste management is monitoring, which is necessary to handle the problems associated with trash generation, collection, transportation, treatment, and disposal procedures. This study examined the technology needed to achieve smart management and proposed using artificial intelligence (AI) to address waste management. Examples of AI technology include convolutional neural networks, which are effective at classifying and identifying waste (Fayomi, et al., 2021).

Waste output rises in tandem with urbanization, affluence, and consumption. Designing and implementing trash collection and management monitoring and management systems is one of the most crucial aspects of sustainable development. For instance, smart waste management (SWM) includes planning and optimizing trash truck routes, managing waste vehicles and urban infrastructure, and gathering and analyzing data from sensors on smart garbage bins (SGBs). This paper's goal is to present a thorough summary of the systems, applications, and methodologies research that has been done in relation to the collecting and processing of solid waste in SWM systems. In order to accomplish this goal, we conducted a thorough literature review. Out of the 3,732 studies that were first obtained from 5 databases, 173 primary studies were chosen for analysis and data extraction in this study. 1) We determined the primary methods and services used in SWM systems at the city and SGB levels; 2) we enumerated sensors and actuators and examined how they are used in different kinds of SWM systems; 3) we enumerated the direct and indirect stakeholders of the SWM systems; 4) we identified the kinds of data that are shared between the SWM systems and stakeholders; and 5) we identified the primary areas of promising research and SWM systems research gaps. We created suggestions for the deployment of city-level and SGB-level SWM systems based on an examination of the current methodologies, tools, and services. (Sosunova & Porras, 2022).

Automated Waste Segregator

The capacity to handle different types of solid waste is constantly growing in the modern world. The largest issue facing the planet now is waste. Up until recently, garbage has not been properly managed. Numerous products and segregation techniques are available for waste management, but only at the industrial level. Waste must be managed, separated, transported, and disposed of appropriately to lower dangers to the public's health and the environment. The greatest way to understand waste's economic worth is to sequester it. The goal of this study is to create an automatic trash segregation system for households and small-town residents. This approach is straightforward and offers a straightforward way to separate waste into three categories: wet waste, solid waste, and metal waste. Here, the Arduino Uno is being used for the segregation process. We utilize an electrical sensor to detect each trash, and tiny mechanical arms are used to separate them. With the goal of recycling the garbage appropriately, this paper will assist society with waste management (Gimonkar, 2021).

According to this study, "Design and Implementation of Automated Trash Bin with Smart Compression" seeks to develop and put into place a productive system that will aid in the appropriate separation of garbage. Two Arduino Unos are connected to one another, and all the elements required to produce the intended result. The type of waste that will be disposed of is determined using push buttons. To show whether the input was valid, LEDs were employed. The garbage cans that are fixed to a circular metal plate rotate thanks to the stepper motor. To ascertain if it was paper or plastic, an ultrasonic sensor was employed. Compressing bins is required (Endaya, 2020)

Sensor

A sensor is an apparatus that recognizes and responds to outside stimuli. The specific input could be movement, pressure, heat, moisture, light, or any of a wide range of other environmental elements. Applications for different kinds of sensors include food analysis, biomolecule research, drug development, crime investigation, clinical diagnosis, environmental field supervision, industrial process regulation, pharmaceutical production, organ replacement, motorsport, agriculture, and aerospace (Subramanian, 2021).

A sensor is an apparatus that receives a stimulus or signal and produces an electrical signal in response to the stimulus. Some types of electrical signals, such voltage or current, are matched by the output signals. The sensor is a device that transforms various signals, such as chemical, biological, or physical signals, into electric signals. Based on the applications, input signal, conversion mechanism, and material utilized, as well as sensor features like cost, accuracy, or range, the sensors are categorized into many types. An overview of sensors and their classifications as mechanical, chemical, magnetic, and optical are provided in this chapter. Along with an introduction to the fundamental types of sensors, the transfer functions, properties, and specifications are also covered (Patel, et al., 2020).

Microcontroller

Modern technology has developed into standalone systems that can perform all required tasks without the need for extra hardware. Microcomputers, usually referred to as single board computers, are the result of advanced microcontrollers. Strong microcontrollers are the source of power for these systems. These microcontrollers can accomplish a wide range of tasks on their own because they have numerous integrated circuits on board. They are employed in a wide range of devices, from basic household appliances to large industrial equipment. There are a wide variety of microcontrollers with varying structures and functions available on the market today. Therefore, selecting the optimal hardware requires a thorough understanding of the ideas around microcontrollers. The fundamental ideas of microcontrollers are presented in this work together with the foundation of their architecture. A comparison of popular single board computers has been provided, along with a discussion of their features and components (Güven, et al., 2017).

Microcontrollers are crucial parts of embedded systems that allow for a wide range of applications across multiple industries. However, there are a lot of elements to take into account, including architecture, peripherals, development environment, and application areas, making it difficult to select the best microcontroller for a certain project. The AVR, 8052, PIC, ESP32, and STM32 are five popular microcontrollers that are thoroughly reviewed and contrasted in this study. It looks at the architecture, peripherals, development environment, and application areas of every microcontroller. In order to help engineers select the ideal microcontroller for their projects, it also offers a comparison that highlights the key distinctions between different microcontrollers. Both novice and seasoned engineers can benefit from this research since it provides a thorough understanding of the many microcontrollers on the market and their uses (Rafique, et al., 2023).

2.2 Related Studies

According to the study entitled "Automatic Waste Segregator and Monitoring System" by Kavya Balakrishnan, Rosmi T.B. Swathy, T.D. Subha, the diseases have developed as a result of poor waste management in metropolitan regions and metropolises brought on by the rapid population growth. In 2006, the total amount of municipal solid garbage generated worldwide was predicted to be 2.02 billion tons. To reduce the dangers to the environment and the general public, trash must be appropriately separated, transported, handled, and disposed of. Our project, "automatic waste segregator and monitoring system," has devised an effective way to dispose of waste. In order to allow garbage to be routed straight to processing, this study suggests an automatic waste segregator (AWS), which is an inexpensive and user-friendly option for a residential segregation system. In order to improve trash management, automatic waste segregators are made to separate waste into three primary categories: plastic, organic, and metallic. In order to monitor the waste collecting process, ultrasonic sensors have been fitted. All of the trash cans would have the sensors installed. A microcontroller will receive a notification when the trash reaches the sensor's level. By employing GSM technology to transmit SMS, the microcontroller will alert the waste collection truck's driver.

According to the study entitled "Automated waste segregation system using Arduino Uno R3" by Siason, Vhie Jaye Marie C, Palomo, Princess Aleya P, Salibio, Michael Georgette S, Ibarra, Adrianne A, Limos-Galay, Jenny A., in order to improve waste management efficiency by separating dry and wet waste materials, this study describes the design and execution of an Automated Waste Segregation System using an Arduino Uno R3. Using an applied research design, the system was created and tested with the use of moisture sensors, infrared obstacle avoidance photoelectric sensors, jumper wires, servo motors, cardboard, storage boxes, and breadboards. Twenty people in all took part in the survey to assess the system's usefulness and efficacy, offering insightful input for improvement. The system's ability to properly separate waste items is demonstrated by the results, which also show that it has the potential to encourage sustainable waste management practices. Waste may be effectively identified and separated using the moisture sensor and the infrared obstacle avoidance photoelectric sensor. Experiments revealed that the automated system separated dry and moist garbage more accurately and efficiently than manual segregation techniques. According to the results, human error was reduced and adequate waste management was ensured as the automated system reliably classified garbage into the right categories. This implies that waste sorting procedures can be enhanced by employing an Arduino Uno R3 for waste segregation, which will help waste management systems adopt more ecologically friendly and sustainable methods. In order to maximize waste segregation operations, future researchers are advised to investigate additional functionalities and further refine the system's features and scalability. By using cutting-edge technical solutions, this study advances sustainable waste management techniques.

According to the study entitled "Literature Review of Automated Waste Segregation System using Machine Learning: A Comprehensive Analysis" by Myra G. Flores, Jose B. Tan Jr., in the modern world, waste management is a major issue that is only getting worse as urbanization increases. An ecological environment is largely dependent on waste management. Sorting at the base level depends on proper garbage disposal at the dumping sites. Sorting rubbish with the traditional method takes longer and requires more workers. Waste can be sorted using a variety of techniques. Using image processing to analyze and categorize the trash can be a very effective method of handling waste. The purpose of this paper is to evaluate the current research that has been presented globally. Additionally, it can determine which method should be applied in a subsequent investigation. These papers discuss the many approaches and suggested systems used for garbage segregation. These also discuss the shortcomings of the algorithms and systems that were already in place. This study provides numerous opportunities to generate new information in the process of developing a new system.

According to the study entitled "AUTOMATIC WASTE SEGREGATION" by C KISHORE, because of the damage they pose to the environment, the dynamic increase in garbage production and the vile dumping of waste have become issues. An automated garbage segregator plays a crucial part in preventing this predicament and making recycling less challenging. Only when garbage is separated does its significance and economic worth become apparent. There isn't a method in place at the moment to separate metal garbage from dry and wet waste. The spot autonomous waste segregation device proposed in this proposal efficiently provides an answer to this issue. A parallel resonance impedance system is employed to separate the metallic trash, and capacitive sensors are used to separate the wet and dry waste. The advantages of this activity include a greater chance of recovery for the waste and a decrease in the occupational risks associated with waste separation for personnel.

According to the study entitled "Automatic Waste Segregator" by A., Sharanya, U., Harika, N., Sriya, & S., Kochuvila, the alarming amount of waste produced daily by humans is the biggest concern that accumulates in India. In metropolitan India, 377 million people generate almost 62 million tons of waste per day, of which 45 million are disposed of in an unsanitary manner, leading to serious health problems and environmental damage. In India, disposal is the final destination for solid waste. Separating the garbage at the disposal level could therefore be a workable solution. The purpose of this paper is to separate the garbage into three main categories: dry, wet, and metallic. The dry waste will then be further separated into paper and plastic.

According to the study entitled "Arduino based Automated Domestic Waste Segregator" by T.M.B.Shankar Balu, R.S. Raghav, K. Aravinth, M. Vamshi, M.E. Harikumar & Rolant Gini J, India is the world's second most populous country. The amount of garbage produced in metropolitan areas has skyrocketed due to rapid urbanization, raising serious concerns. The majority of them are directly disposed of in landfills without being properly treated or segregated. Many issues arise as a result of this behavior. Contamination of groundwater occurs. These landfills provide as ideal habitats for stray dogs, rats, and insects. Exposure to these wastes causes numerous health issues for rag pickers and conservancy employees. Segregation should be implemented at different levels to address this problem. The source itself is the crucial level of segregation (Balu, et al., 2022).

CHAPTER III

METHODOLOGY

3.1 Research Design

This study aims to develop an automated waste segregator with sensor-based detection for enhanced disposal using a developmental-experimental research design. The researchers aim to evaluate how their prototype contributes to improving public health. Thus, it will go on through a long process on how to accurately segregate waste like biodegradable and non-biodegradable and recyclable types of waste.

The developmental-experimental research design is to be used in order to make an automated waste segregator that will help reduce manual labor for the users and waste collectors. This study will have a big impact on having an innovative and easy waste segregation.

3.2 Materials Used

3.2.a. Hardware

1. Arduino Uno

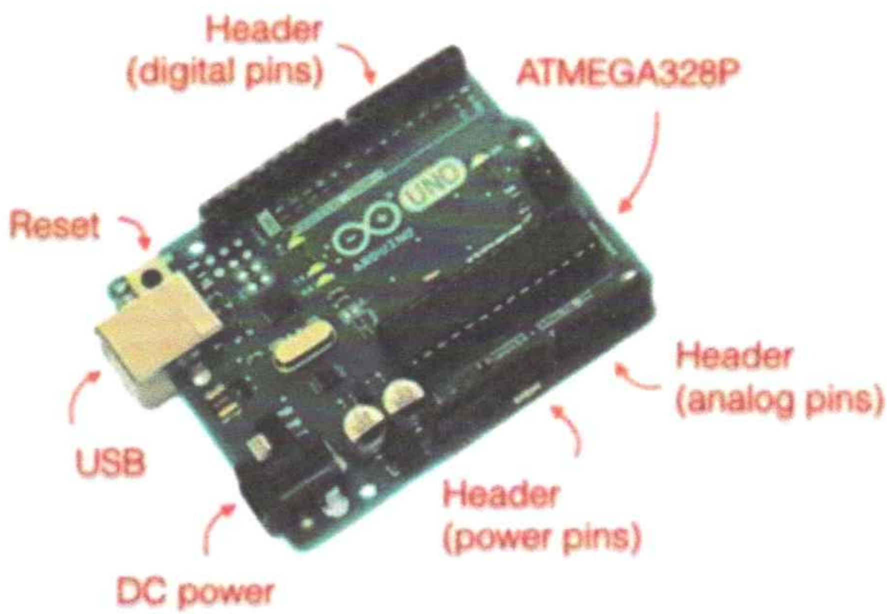


Figure 1: Arduino Uno

PARTS:

Header Pins On - The rows of connections on an Arduino Uno let you connect wires and electronic components to the board (Adafruit Learning System, 2016).

Reset - To "reset" the microcontroller, you must restart it and run the code from the start (Arduino Support, n.d.).

USB Port - acts as an interface for power and communication. The user can: Transfer code (sketches) to the Arduino board from a computer. Usually, 5V is used to power the Arduino board, which often eliminates the requirement for an extra power source (Arduino2go, 2016).

DC Power- The term "direct current power" describes the kind of electrical current that powers the board, usually via a USB connection or a barrel jack (Docs Arduino, n.d.).

Header Power Pins - To power the board and external components, supply a variety of voltage and ground connections (Docs Arduino, n.d.).

Header Analog Pins - Analog voltage signals, like those from sensors, are read via these pins and transformed into digital values that the microcontroller can comprehend (Docs Arduino, n.d.).

The ATMEGA328P - The Arduino Uno board's key component is the microcontroller chip (Qoura, n.d.).

The widely used board, sometimes referred to as the "classic Arduino," is the Arduino UNO. There are 14 digital I/O pins on this board, including 6 PWM-capable pins, 6 analog inputs, a reset button, a power jack, a USB port, and more. Arduino shields enable this board to send and receive data via the internet (Louis, 2018).

2. Humidity Sensor

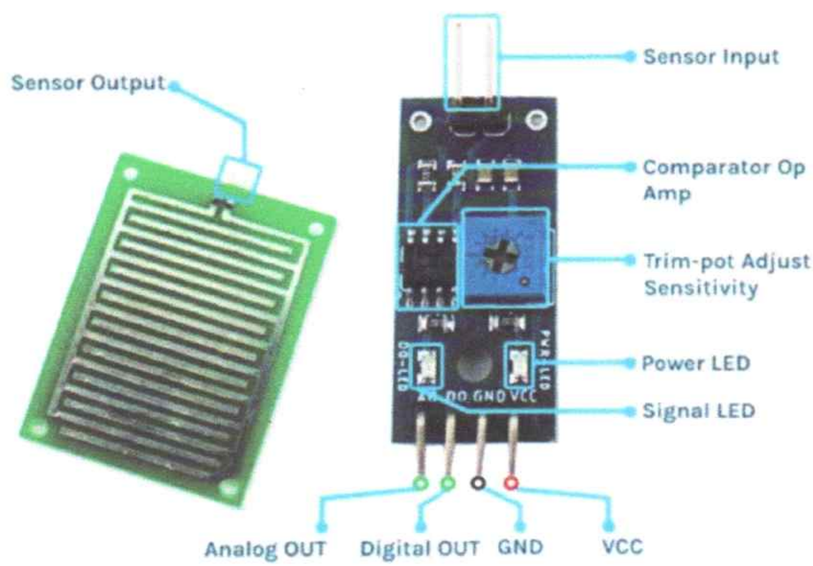


Figure 2: Humidity Sensor

PARTS:

Sensor Output - Through the movement of electrons, the information is transferred and processed in electrical form. A sensor is a device that reacts to a stimulus or signal by sending out an electrical signal (Science Direct, 2001).

Sensor Input – Changes in light, heat, motion, pressure, or chemical composition are all detected by sensors (Christ & Wernli, 2014).

Comparator Op Amp - An output signal produced by a comparator shows which of two input signals has a higher voltage. Because an op-amp combines a differential input stage with extremely high gain, it can be used as a comparator (Keim, 2020).

Trim-pot Adjust Sensitivity - Trim pots, also known as trimmer potentiometers, are tiny, movable resistors that are used to regulate circuits. It works as a variable voltage divider, enabling accurate resistance or voltage modifications inside a circuit (Reddit, n.d.).

Power LED - is a visual cue that indicates if a device is getting electricity. It is frequently seen on laptops, PCs, and other electronic devices, and it illuminates to indicate that the item is turned on. With blinking patterns suggesting possible startup problems, it can also serve as a diagnostic tool (Wikipedia contributors, 2025).

Signal LED - A semiconductor device known as a Signal LED, or Light Emitting Diode, generates light when an electric current flows through it. From traffic lights and machine status indicators to remote controls and even smartphone backlighting, it serves a variety of signaling and indication functions. LEDs are adaptable for a variety of applications since they are long-lasting, energy-efficient, and come in a wide spectrum of colors (Intelligence in Light, n.d.).

Analog Out - The act of turning digital data into a continuous, changeable electrical signal—usually voltage or current—is known as analog output. Motors, valves, and displays are just a few examples of the external systems or devices that can be controlled by this signal. In essence, it's a means of bridging the gap between analog devices that require control in the real world and digital control systems (Fernandez & Dang, 2013).

Digital Out - In control systems such as PLCs, a digital output (DO) is a binary output signal (0 or 1) that regulates the on/off status of external devices. It functions similarly to a switch, enabling a system to control valves, relays, lamps, and other actuators as well as turn equipment on and off (Help Center, 2025).

GND - Ground, or GND for short, is a frequent reference point in electrical and electronic circuits that allows the circuit to operate safely and correctly. In addition to serving as a voltage reference and a return path for electrical current, it also reduces electrical noise and risks (Staff, 2024).

VCC- Specifically in Singapore, a Variable Capital Company (VCC) is a business structure intended for investment funds. It permits capital structure flexibility, allowing shares to be issued and redeemed without requiring frequent regulatory permissions. VCCs allow asset and liability segregation for each sub-fund and can be set up as umbrella organizations with several sub-funds or as stand-alone funds (Qoura, n.d.).

The performance of a humidity sensor is mostly dictated by its nano- and microscopic structure, which comprises electrode distance, pore size, layer thickness, size distribution of the surface structural element, and uniformity of surface morphology. Porous films have been found to be more sensitive to humidity than their nonporous equivalents. The regularity and controllability of porous structures are therefore crucial considerations in sensor design (Blank, et al., 2016).

3. Inductive Proximity Sensor

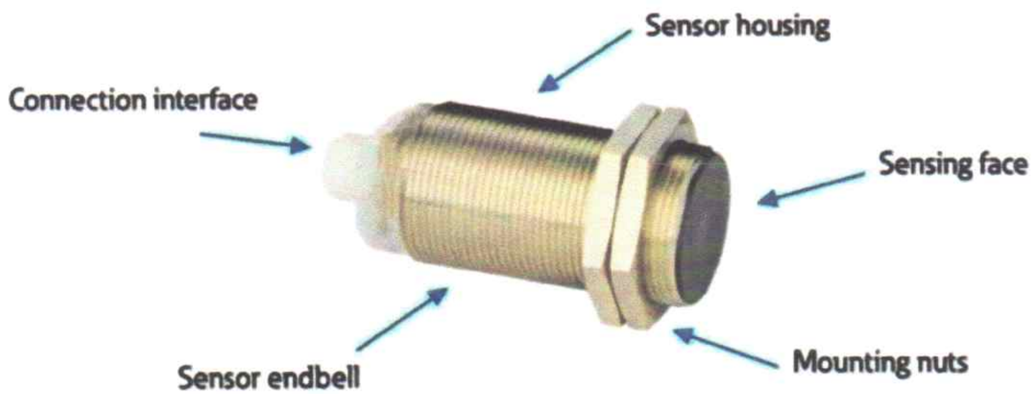


Figure 3: Inductive Proximity Sensor

PARTS:

Sensor Housing - A sensor housing is a protective shell made to encapsulate and shield a sensor, guaranteeing its dependable performance in a range of environmental circumstances. It protects against environmental elements like moisture, dust, and physical harm and may make it easier to integrate sensors into a system (Contentartists, 2025).

Sensing Face - An inductive sensor's sensing face is the surface from which it emanates an electromagnetic field, which is used to find metallic objects. The presence of the object is indicated by a change in the sensor's output signal caused by the disruption of the field caused by a conductive metal object entering this field (Latest News from Seed Studio, 2019).

Mounting Nuts - A common technique for assembling mechanical parts, nut mounting is essential for holding pieces together. Engineers can boost the stability, simplicity of assembly, and diversity of their designs by using nuts as fasteners. Nut mounting provides a dependable and effective solution that has proven essential in many industries, whether it is used to unite two pieces, secure panels, or provide adjustable connections (MISUMI, 2024).

Connection Interface - Anything that interferes with a computer connection is referred to as a connection interface. Interferences can be extremely important, particularly when it comes to connectivity. These linkages aren't limited to intangible variables; physical interferences can also occur, allowing physical items to communicate with computers and establish relationships (ExamCollection, n.d.).

Sensor Endbell - A sensor endbell is a part that is frequently seen on proximity sensors. It usually contains the connection interface for wiring the sensor as well as indicator lights, such as LEDs. It enables connecting to external devices or systems and gives a visible indication of the sensor's condition (Latest News from Seed Studio, 2019).

In many technical goods and systems, inductive proximity sensors are utilized to measure the position and movement of objects or targets without making contact. They are used in many different application areas, including manufacturing lines, robots, transportation, telecommunication, and security. The resilience, high precision, and low sensitivity of the inductive sensing principle to harsh environmental conditions and extreme operating circumstances, such as cryogenic temperatures, are well-known. Inductive proximity sensors typically have a measuring range of 0.1 to 5 cm. Due to the large number of components that make up these sensors, the overall size of the smallest inductive proximity sensors, including the sensing coil and the electronic circuit interface, are rarely less than a few cubic centimeters (Passeraub, 1999).

4. Stepper Motor

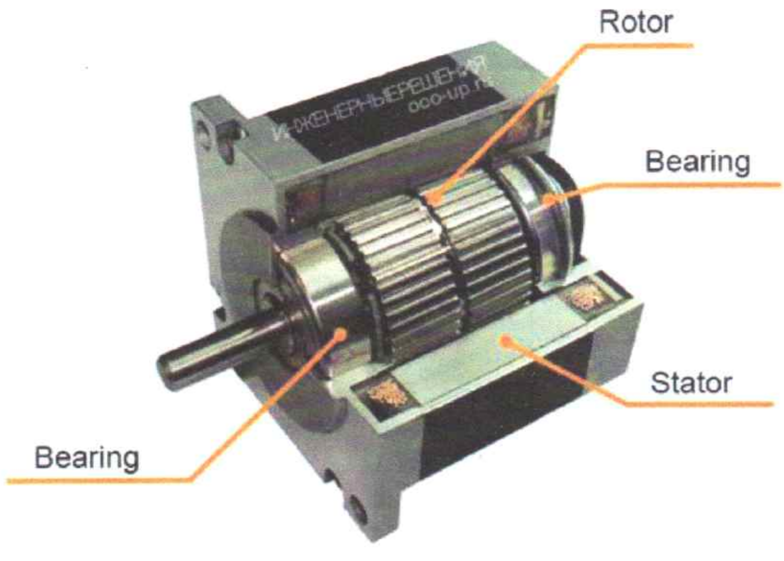


Figure 4: Stepper Motor

PARTS:

Rotor – A stepper motor's rotor is a rotating part that interacts with the stator's magnetic field to produce precise, distinct movements. Typically, this component is a toothed ferromagnetic structure or a shaft with permanent magnets (Oriental Motor, n.d.).

Bearing – to lessen friction while in use and support the rotating shaft. For applications like robotics, 3D printers, and precision machinery, these bearings guarantee accurate and dependable movement. The bearings reduce the motor's wear and tear and assist keep the shaft aligned (Duet3D, 2022).

Stator – The stationary component of a stepper motor that contains the windings and poles (electromagnets) that generate the magnetic field is called the stator. It is usually a cylindrical shape. It is the part that creates the stepping action by interacting with the rotor. The motor's performance characteristics are directly impacted by the stator's design, which includes the number of phases and poles (monolithicpower, n.d.).

A stepper motor, sometimes referred to as a step motor or stepping motor, is a brushless DC special electric motor that moves in discrete increments by dividing a whole rotation into several equal steps. You may get extremely accurate positioning and speed regulation using computer-controlled stepping (Al-Naib, 2019).

5. Stepper Motor Driver

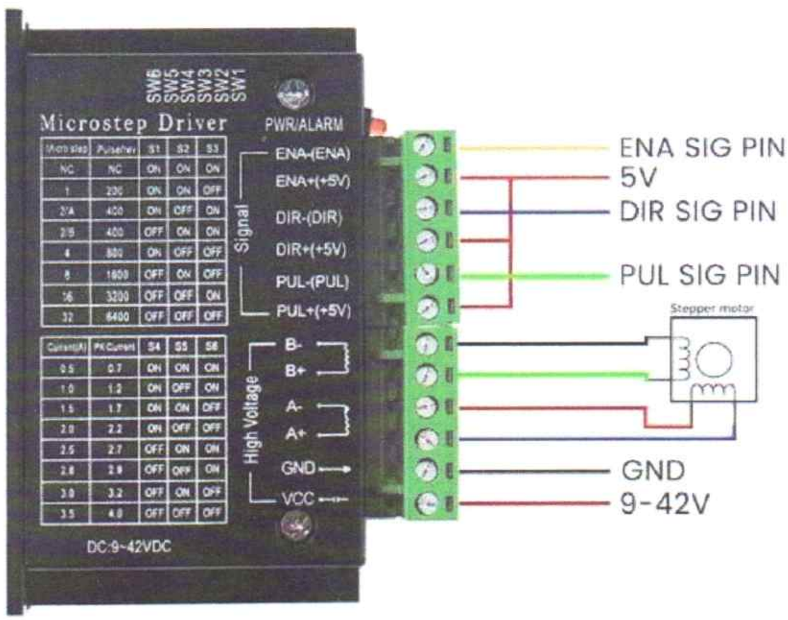


Figure 5: Stepper Motor Driver

PARTS:

Ena Sig Pin - (ENA) The module's negative enable pin. 2. The module's +5V pin is the ENA+ (+5V) Positive Enable pin (Limited, n.d.).

5V – A TB6600 stepper motor driver's 5V designation denotes the voltage level at which control signals are transmitted from a microcontroller (such as an Arduino) to the driver (circuitrocks, n.d.)

Dir Sig Pin – Step and direction (dir) inputs are the motor's two inputs in this mode. A pulse signal that determines the rotational angle and speed is accepted by the step input. The direction input controls the rotational direction by receiving a high or low digital signal (Knowledge Article, 2020).

Pul Sig Pin – Stepper motors get its name from the fact that they move one step with every electrical pulse. A driver controls stepper motors by sending pulses into the motor, which causes it to rotate. The number of pulses sent into the driver equals the number of pulses the motor rotates (Oriental Motor, n.d.).

GND – Provide a ground reference. The A- and B- ports are internally connected to GND when the external power supply mode is selected. Positive supply voltages must be supplied, and the supply must always be connected (a series switch between the supply and the driver, for instance, is not permitted) (MATLAB, n.d.).

9-42v - The 9-42V specification for a stepper motor driver describes the input voltage range that the driver is intended to function in. In order to power the stepper motor, it shows the lowest and highest DC voltage that can be safely given to the driver (Micro Steps, n.d.).

A unique driver, a control amplifier that energizes each motor winding in turn, is necessary for the stepper motor to operate normally. The following will present three stepper motor drive circuits, the first two of which are solely driven by the special chip, and the third of which is driven by the microcontroller and special chip together. Currently, the stepper motor is primarily controlled and driven by a special chip or microcontroller (Chang, 2023).

6. IR Sensor

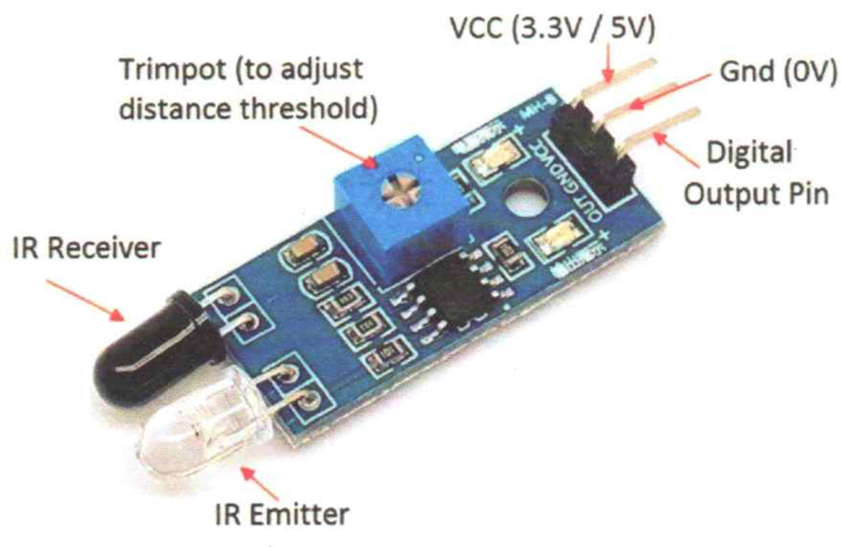


Figure 6: IR Sensor

PARTS:

IR Emitter - An element that emits infrared light is referred to as an IR emitter in the context of an IR (infrared) sensor. Infrared radiation, which is invisible to the human eye, is produced by a particular light-emitting diode (LED). The infrared sensor then uses this light to detect things, measure distances, or detect environmental changes (Qoura, n.d.).

IR receiver LED - An IR receiver is a part of an IR (infrared) sensor that picks up signals of infrared light. It is basically the sensor's "eye" and is in charge of detecting infrared radiation that is reflected off of objects or released by a transmitter. After that, the receiver transforms the light signal into an electrical signal that other sensor parts or an external device can process (Mróz, 2024).

Trimpot (to adjust distance threshold) - A trimpot, also called a trimmer potentiometer, is a tiny potentiometer used in circuits for calibration, tuning, and adjustment (EE POWER, n.d.).

Digital Output Pin - A digital output pin on an infrared (IR) sensor signal whether an obstruction is within its detecting range or not. It indicates whether an infrared beam is reflected back to the sensor with a binary signal, usually HIGH (1) or LOW (0) (Instructables, 2024).

To detect a specific light wavelength in the infra-red (IR) spectrum, an infrared sensor uses a select-light sensor. We are currently surrounded by electronics and communication equipment, including infrared sensors, which are used in a wide range of applications. Any mobile device that has an infrared sensor blaster capability can be used with any electrical equipment, and these devices are all connected to the same device, which is your phone. Infrared radiation from a basic paper-made device that becomes more conductive when it comes into contact with a heated item is discussed in this work (Ajmera & Vivekananda, 2017).

7. Ultrasonic Sensor

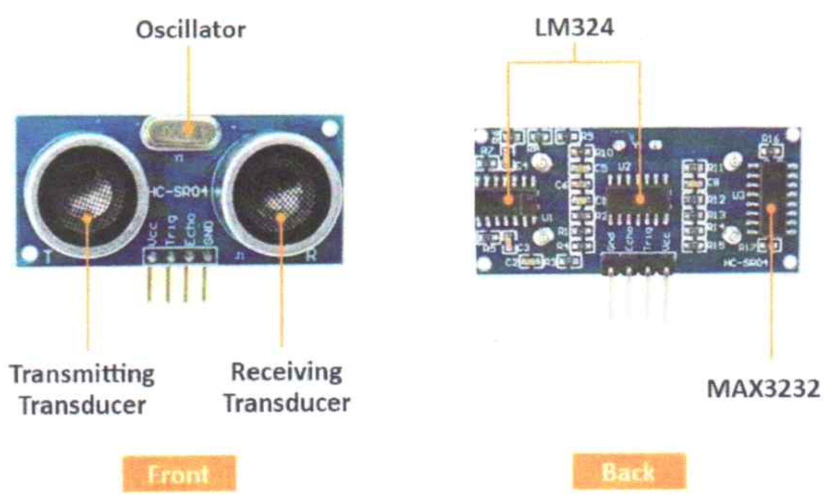


Figure 7: Ultrasonic Sensor

PARTS:

Oscillator – An oscillator, also known as an active surface, ceramic converter, or transducer, is the sensor surface that produces the sound signal in an ultrasonic sensor (wenglor, n.d.).

Receiving & Transmitting Transducer – Transducers for sending and receiving: The sensor's transducer functions as a microphone to send and receive ultrasonic sound. Like many others, our sensors send a pulse and receive the echo using a single transducer. By measuring the intervals of time between delivering and receiving the ultrasonic pulse, the sensor calculates the distance to a target (MaxBotix, n.d.).

LM324 – An operational amplifier that can be used in a variety of circuit types is the LM324 circuit. It has low static power consumption, compatibility with a single power supply, and a wide variety of power supply alternatives (OurPCB, n.d.).

MAX3232 – The kind and use of the sensor determine the range of ultrasonic sensors. The majority of ultrasonic sensors typically have a range of 2 cm to 10 meters. Low-frequency ultrasonic sensors have a range of 4 to 10 meters and operate at frequencies ranging from 20 kHz to 80 kHz (Boqu, 2024).

Similar to sonar detectors, ultrasonic sensors operate by sending out a sound pulse that is inaudible to humans. This pulse moves at the speed of sound (340 m/s) along a conical path away from the range finder. The range finder receives the sound after it bounces off an object. The sensor determines the time difference between transmitting the signal and receiving the echo after interpreting this as an echo. A controller then calculates this interval to find the object's distance (Fares, 2020).

8. Buzzer

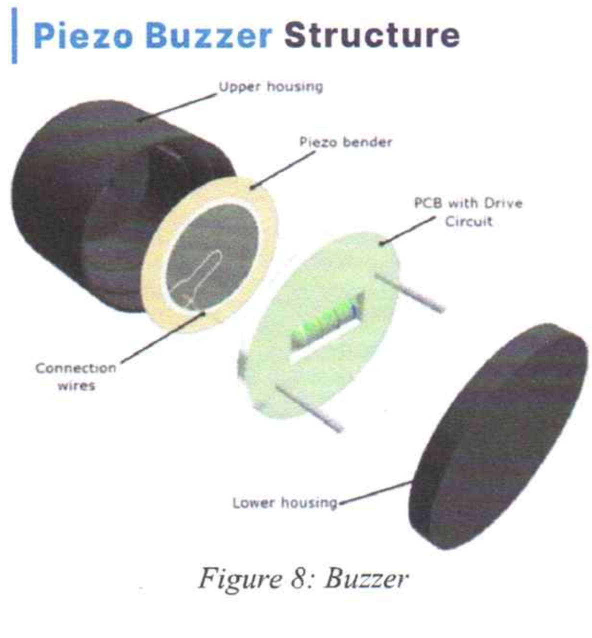


Figure 8: Buzzer

PARTS:

Upper and Lower Housing - Passive buzzers are frequently utilized in projects requiring changeable sound frequencies or melodies. They are frequently contained in protective casings and occasionally have a jumper housing for convenient connection (Voltaat, n.d.).

Piezo Bender - A piezoelectric device known as a piezo bender bends when an electrical voltage is applied between its plates. On the other hand, an electrical potential is produced when a piezo bender bends. Several rectangular layers of piezoelectic material with polarization perpendicular to the stack make up a piezo bender (MATLAB, n.d.).

Connection Wires - Two pins make up a passive buzzer: one is connected to ground and the other to a digital output pin on a microcontroller such as an Arduino. To generate sound, the microcontroller then transmits a pulsed signal—typically a PWM (Pulse Width Modulation) signal—to the buzzer in the form of a sequence of on/off cycles (OSHWLab, n.d.).

PCB with Drive Circuits - Transistors, resistors, and occasionally capacitors are parts of a PCB with drive circuits for a passive buzzer, which creates the oscillating signal required to make the buzzer sound. Passive buzzers need an external circuit to generate the oscillating voltage or current necessary for them to operate, in contrast to active buzzers, which have internal oscillators (Grillon, 2018).

Piezo and magnetic technologies are the two most frequently utilized in buzzer designs. Both magnetic and piezo buzzers are used in various applications, but the choice between the two technologies depends on a variety of factors. While piezo buzzers typically have a higher maximum sound pressure level (SPL) capability than magnetic buzzers, magnetic buzzers function at lower voltages and higher currents (1.5~12 V, > 20 mA) than piezo buzzers (12~220 V, < 20 mA). It should be mentioned, nevertheless, that larger footprints are necessary to achieve the higher SPL that piezo buzzers offer (Grillone, 2018).

9. Servo Motor

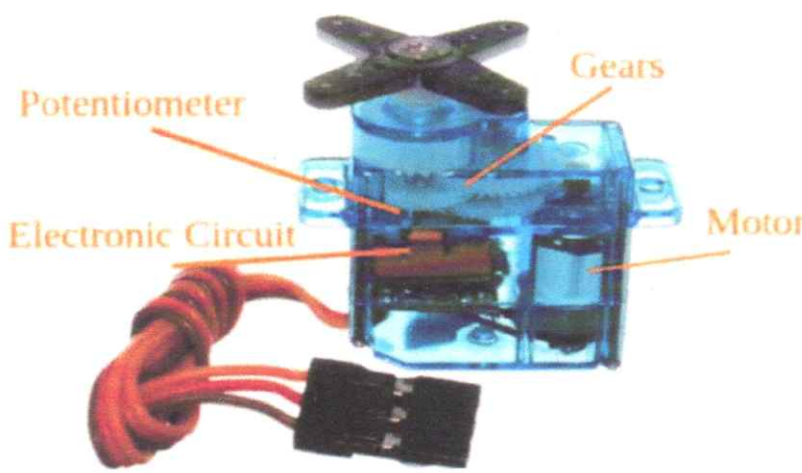


Figure 9: Servo Motor

PARTS:

Potentometer - In the feedback loop, the potentiometer serves as a position sensor (JAMECO, n.d.).

Motor - The electronic circuit in a servo motor serves as the "brain," regulating the motor's position in response to electrical impulses (JAMECO, n.d.).

Gears - Gears are essential for changing the internal motor's high-speed, low-torque output into a slower, higher-torque output that may be used for precise movements (Helen, 2022).

Electric Circuit - In order to carry out different experiments and tasks, electronic components including wires, resistors, capacitors, and coils are connected on a breadboard (Fernandez & Dang, 2013).

One kind of electromotor that has highly accurate shaft control is a servomotor. A servomotor's shaft can revolve at the desired angle or at a steady speed. Because of these characteristics, servomotors are now widely used in robotics. A DTC motor, gearbox with shaft, and controller with required sensors (encoder, position sensor, etc.) make up a servomotor (Autsou, et.al., 2024).

10. 3.7v Battery

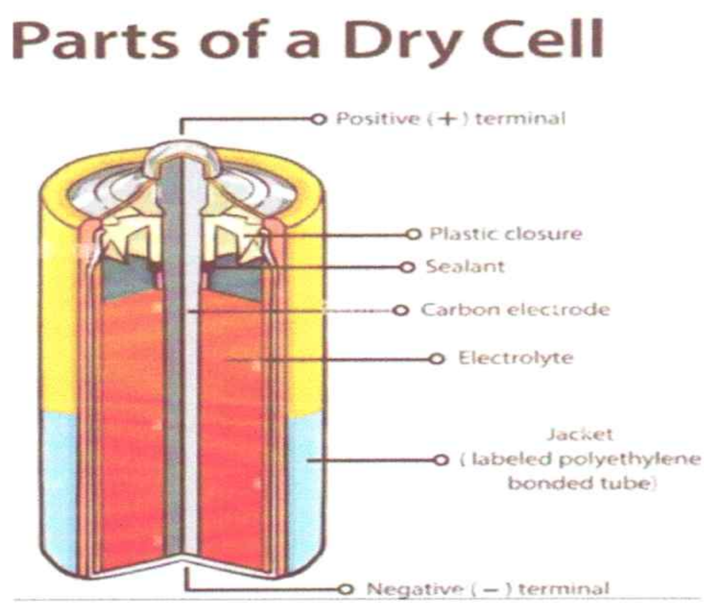


Figure 10: 3.7v Battery

PARTS:

Positive (+) Terminal - Electrons enter a battery at the positive terminal, also known as the cathode, and exit the battery through the negative terminal, also known as the anode (BioLogic, 2024).

Plastic closure - prevents damage and short circuits by shielding a battery cable termination (Lacivita, 2024).

Sealant- There is no opening for adding acid to this valve-regulated lead-acid battery (Clark, 1990).

Carbon electron- One of the two terminals (anode or cathode) for the flow of electrical current within the battery's electrochemical cell is a carbon electrode, which is a conductive substance composed of carbon (Wikipedia contributors, 2025).

Electrolyte- This valve-regulated lead-acid battery has no opening for the addition of acid (Matseed, n.d.).

Essentially a rechargeable lithium-ion cell, a 3.7V battery maintains a nominal voltage of 3.7 volts for the most of its discharge cycle. These batteries are perfect for delicate electronics that need steady power delivery because of their constancy. These batteries normally charge to about 4.2V when full and drain to about 3.0V when depleted, despite having a nominal voltage of 3.7V (Lukas, 2025).

11. Battery Holder

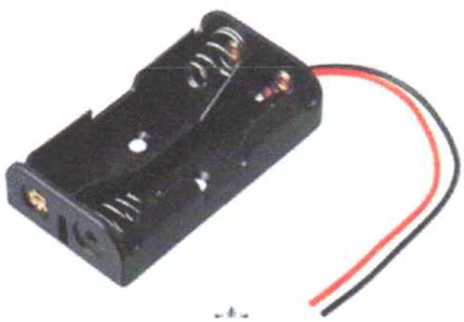


Figure 11: Battery Holder

Electric vehicles are powered by a lithium-ion battery pack made up of battery modules. A battery holder was created to support and safeguard each lithium-ion battery in order to guarantee that these batteries in battery modules are properly safeguarded. The battery pack will be impacted by harsh conditions while the vehicle is operating, such as shocks from bumps in the road and changes brought on by the state of the road surface (Bao & Zhao, 2018).

12. Breadboard

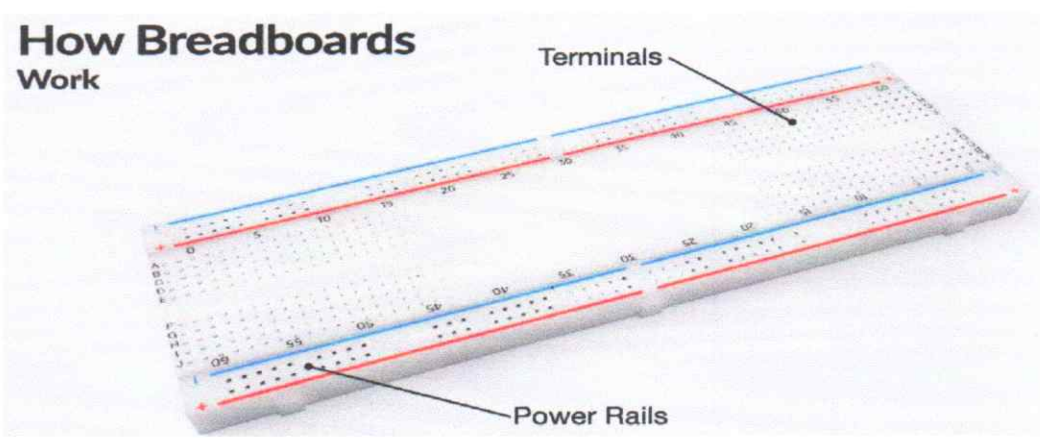


Figure 12: Breadboard

PARTS:

Power Rails - Typically denoted by red and blue lines, these are the rows of holes that run down the breadboard's top and bottom. The ground or negative voltage is shown by the blue line, and the positive voltage source is shown by the red line.

Terminals – These are the breadboard's central rows of holes. They serve as the main component of your circuit by joining separate parts.

In essence, a breadboard, also known as a protoboard, serves as the framework for building and prototyping electronics. Building temporary electronic circuits or conducting circuit design experiments is made simple and quick with a breadboard. The rows and columns of internally connected spring clips beneath the perforated plastic casing of a breadboard allow engineers to quickly connect wires or components. The spring clip holes that make up the grid are precisely 0.1 inches apart in both X and Y directions (Fernandez & Dang, 2013).

13. Jumper Wires

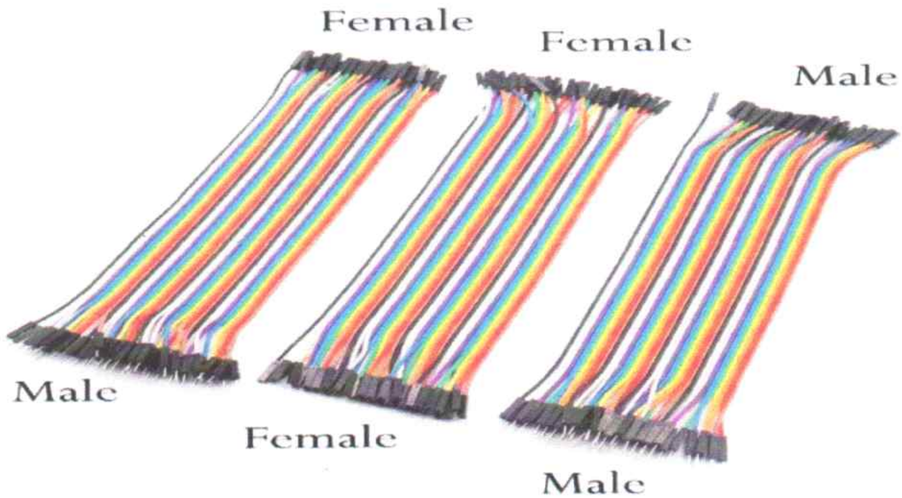


Figure 13: Jumper Wires

PARTS:

Male to Male Jumper - Both connectors are male and are called plugs.

Male to Female Jumper – The male connector serves as a plug while the other one is a jack.

Female to Female Jumper – Both connectors are female and are called jack.

Jumpers are typically small metal connections that are used to open or close circuit components. An electrical circuit board is regulated by its two or more connection points. They are responsible for configuring the motherboard and other computer devices. Assume that intrusion detection was provided by your motherboard. It can be turned on or off with a jumper. Electrical cables having connection pins on both ends are known as jumpers. They are employed in circuits to join two places without the need for solder. Jumper wires can be used to detect circuit issues or make modifications to a circuit. Additionally, they work best when employed to avoid a suspected problematic section of the circuit that lacks a resistor (Seotechwriter, 2023).

14. PVC Pipe

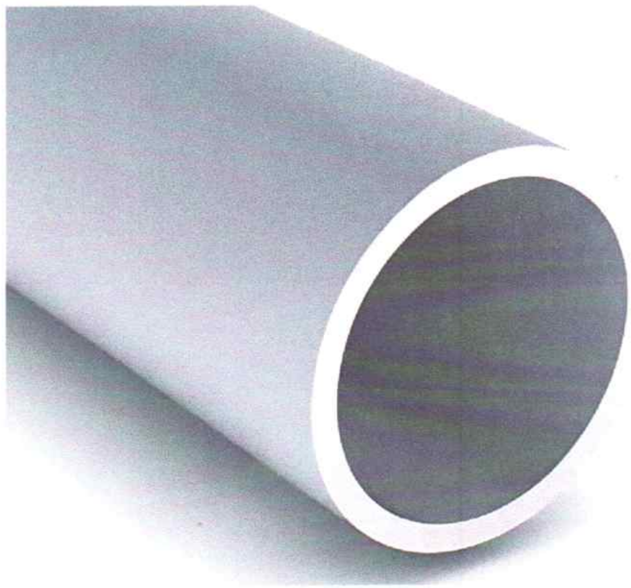


Figure 14: PVC Pipe

Numerous commercial and industrial pipe applications employ plastics. The most well-known are glass-fibre-reinforced polyester (GRP or FRP), polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), acryliconitrile-butadiene-styrene (ABS), and polybutylene (PB). PVC, PE, and PP are the most widely used polymer materials when it comes to piping systems for gas distribution, drinking water supply, and sewage disposal (Makris, et al., 2019).

15. Plywood

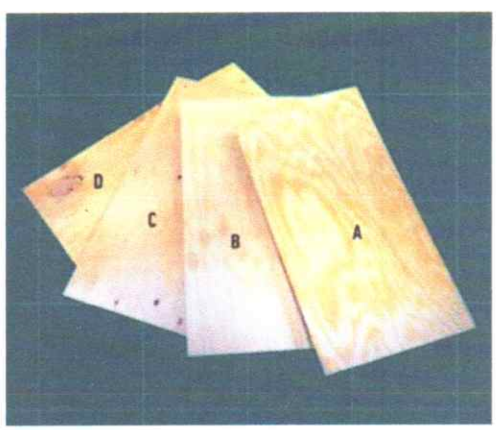


Figure 15: Plywood

Wood, a naturally occurring renewable resource, is the most crucial raw element for plywood. Deciduous (beech, poplar, birch, and other) and coniferous (spruce, pine, etc.) veneers are used to make plywood. The typical plywood is composed of thin veneers with several cross bands. A variety of oriented special constructions targeted at particular end users are available in addition to the typical cross-banded structure (Omer, et al., 2005).

16. Plastic Bottle

Figure 16: Plastic Bottle

Plastic water bottles are now a necessary component of our contemporary way of life. They are a well-liked option for getting access to clean drinking water because of their availability, price, and simplicity. Plastic bottles are practical for a variety of locations, including homes, workplaces, gyms, and outdoor activities, because they are lightweight, strong, and portable. But the excessive and pervasive usage of plastic water bottles have sparked serious worries about how they affect the environment (Pandey, 2023).

3.2.b. Software

1. Arduino IDE

The Arduino development board is a piece of hardware, and the Arduino IDE (Integrated Development Environment) is software used to write code. These microcontrollers are built with either a 32-bit Atmel ARM or an 8-bit Atmel AVR microcontroller, which may be readily programmed using the C or C++ language in the Arduino IDE (Louis, 2016).

3.3 Experimental Procedure

The study aims to develop and test how accurately an automated waste segregator will identify three categories: biodegradable, non-biodegradable, and recyclable wastes. The system was built using different kinds of materials like Arduino Uno, an inductive sensor, and a humidity sensor. The Arduino Uno serves as a microcontroller, the inductive sensor will be used in identifying metallic waste, and the humidity sensor is the one to use in identifying biodegradable waste.

In the segregation part, we have what we call a smart sorting tube that contains sensors for detecting metal and moisture content. Based on the system, we use a servo motor that directs the waste to the right trash bin, while the classification of the trash was programmed into Arduino using Arduino IDE.

The system was tested indoors with 9 pieces of waste, that is, 3 in each category. Each waste was put into the smart tube, sorting one at a time at 5-second intervals. The environment around the prototype was enclosed and had the proper lighting and temperature to avoid the interference of the sensor.

3.4 Data Collection

Data collection in an automatic waste segregation system is performed by interfacing electronic sensors with a microcontroller (Arduino Uno). The system consists of sensors and controllers that identify waste types: organic, metallic, and plastic, based on measurable physical properties. Following are the descriptions of how data is collected with each of these components:

3.4.1.a. IR Sensor

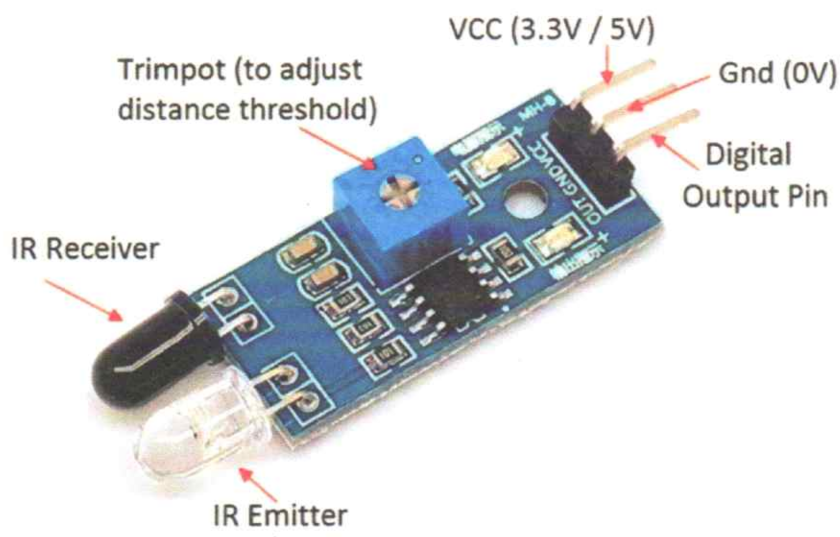


Figure 17: IR Sensor

PARTS:

IR Emitter - An element that emits infrared light is referred to as an IR emitter in the context of an IR (infrared) sensor. Infrared radiation, which is invisible to the human eye, is produced by a particular light-emitting diode (LED). The infrared sensor then uses this light to detect things, measure distances, or detect environmental changes (Qoura, n.d.).

IR receiver LED - An IR receiver is a part of an IR (infrared) sensor that picks up signals of infrared light. It is basically the sensor's "eye" and is in charge of detecting infrared radiation that is reflected off of objects or released by a transmitter. After that, the receiver transforms the light signal into an electrical signal that other sensor parts or an external device can process (Mróz, 2024).

Trimpot (to adjust distance threshold) - A trimpot, also called a trimmer potentiometer, is a tiny potentiometer used in circuits for calibration, tuning, and adjustment (EE POWER, n.d.).

Digital Output Pin - A digital output pin on an infrared (IR) sensor signal whether an obstruction is within its detecting range or not. It indicates whether an infrared beam is reflected back to the sensor with a binary signal, usually HIGH (1) or LOW (0) (Instructables, 2024).

The IR sensor indicates the presence of an object. When an object is placed on the system, the IR sends an infrared beam upon positioning and receives a reflected signal. The intensity of the reflected signal helps determine if an object exists, which will then help the system analyze the object further (Instructables, 2021).

3.4.2.b. Humidity Sensor

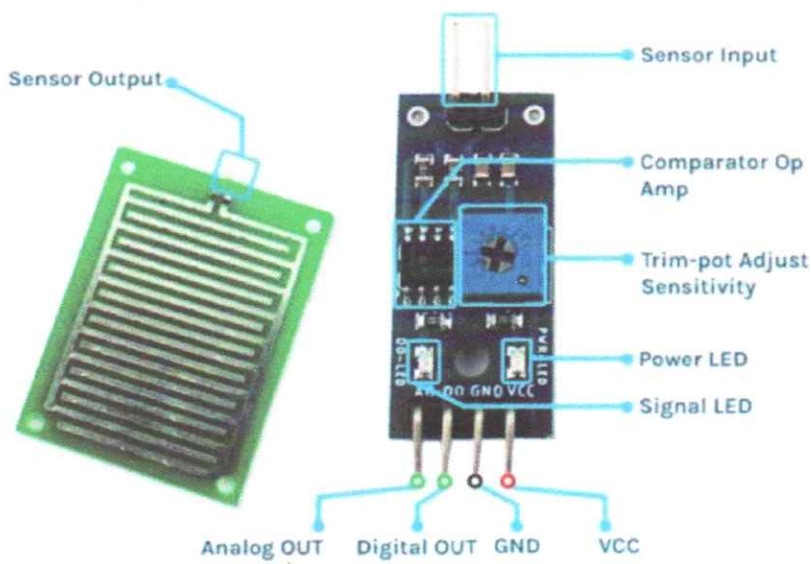


Figure 18: Humidity Sensor

PARTS:

Sensor Output - Through the movement of electrons, the information is transferred and processed in electrical form. A sensor is a device that reacts to a stimulus or signal by sending out an electrical signal (Science Direct, 2001).

Sensor Input – Changes in light, heat, motion, pressure, or chemical composition are all detected by sensors (Christ & Wernli, 2014).

Comparator Op Amp - An output signal produced by a comparator shows which of two input signals has a higher voltage. Because an op-amp combines a differential input stage with extremely high gain, it can be used as a comparator (Keim, 2020).

Trim-pot Adjust Sensitivity - Trim pots, also known as trimmer potentiometers, are tiny, movable resistors that are used to regulate circuits. It works as a variable voltage divider, enabling accurate resistance or voltage modifications inside a circuit (Reddit, n.d.).

Power LED - is a visual cue that indicates if a device is getting electricity. It is frequently seen on laptops, PCs, and other electronic devices, and it illuminates to indicate that the item is turned on. With blinking patterns suggesting possible startup problems, it can also serve as a diagnostic tool (Wikipedia contributors, 2025).

Signal LED - A semiconductor device known as a Signal LED, or Light Emitting Diode, generates light when an electric current flows through it. From traffic lights and machine status indicators to remote controls and even smartphone backlighting, it serves a variety of signaling and indication functions. LEDs are adaptable for a variety of applications since they are long-lasting, energy-efficient, and come in a wide spectrum of colors (Intelligence in Light, n.d.).

Analog Out - The act of turning digital data into a continuous, changeable electrical signal—usually voltage or current—is known as analog output. Motors, valves, and displays are just a few examples of the external systems or devices that can be controlled by this signal. In essence, it's a means of bridging the gap between analog devices that require control in the real world and digital control systems (Fernandez & Dang, 2013).

Digital Out - In control systems such as PLCs, a digital output (DO) is a binary output signal (0 or 1) that regulates the on/off status of external devices. It functions similarly to a switch, enabling a system to control valves, relays, lamps, and other actuators as well as turn equipment on and off (Help Center, 2025).

GND - Ground, or GND for short, is a frequent reference point in electrical and electronic circuits that allows the circuit to operate safely and correctly. In addition to serving as a voltage reference and a return path for electrical current, it also reduces electrical noise and risks (Staff, 2024).

VCC- Specifically in Singapore, a Variable Capital Company (VCC) is a business structure intended for investment funds. It permits capital structure flexibility, allowing shares to be issued and redeemed without requiring frequent regulatory permissions. VCCs allow asset and liability segregation for each sub-fund and can be set up as umbrella organizations with several sub-funds or as stand-alone funds (Qoura, n.d.).

The humidity sensor gives a reading in relation to the moisture content of the waste material. If it is high, then generally, it is an indication of organic or biodegradable material; if the reading is low, the material could be dry, such as plastic or metal. This reading helps differentiate organic waste from inorganic (Instructables, 2025).

3.4.3.c. Inductive Proximity Sensor

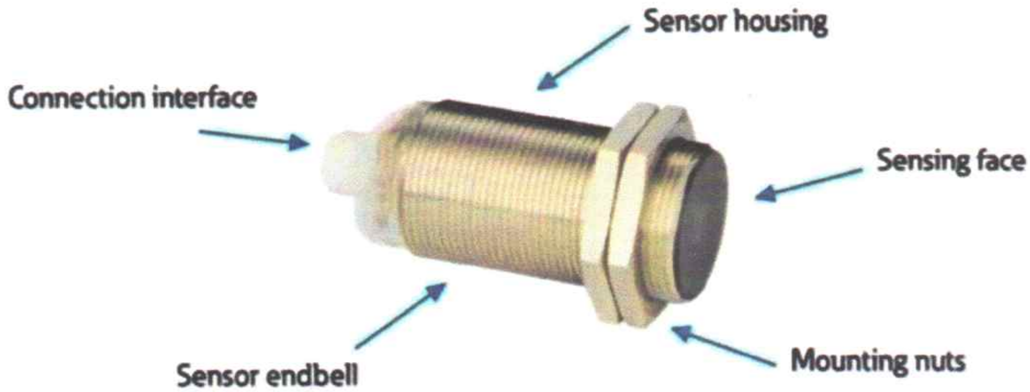


Figure 19: Inductive Proximity Sensor

PARTS:

Sensor Housing - A sensor housing is a protective shell made to encapsulate and shield a sensor, guaranteeing its dependable performance in a range of environmental circumstances. It protects against environmental elements like moisture, dust, and physical harm and may make it easier to integrate sensors into a system (Contentartists, 2025).

Sensing Face - An inductive sensor's sensing face is the surface from which it emanates an electromagnetic field, which is used to find metallic objects. The presence of the object is indicated by a change in the sensor's output signal caused by the disruption of the field caused by a conductive metal object entering this field (Latest News from Seed Studio, 2019).

Mounting Nuts - A common technique for assembling mechanical parts, nut mounting is essential for holding pieces together. Engineers can boost the stability, simplicity of assembly, and diversity of their designs by using nuts as fasteners. Nut mounting provides a dependable and effective solution that has proven essential in many industries, whether it is used to unite two pieces, secure panels, or provide adjustable connections (MISUMI, 2024).

Connection Interface - Anything that interferes with a computer connection is referred to as a connection interface. Interferences can be extremely important, particularly when it comes to connectivity. These linkages aren't limited to intangible variables; physical interferences can also occur, allowing physical items to communicate with computers and establish relationships (ExamCollection, n.d.).

Sensor Endbell - A sensor endbell is a part that is frequently seen on proximity sensors. It usually contains the connection interface for wiring the sensor as well as indicator lights, such as LEDs. It enables connecting to external devices or systems and gives a visible indication of the sensor's condition (Latest News from Seed Studio, 2019).

Without direct contact, the sensor detects metallic objects. An electromagnetic field produces an eddy current is sensed by the very same field produced within the target metal (Shojaei, 2024).

3.4.4.d. Ultrasonic Sensor

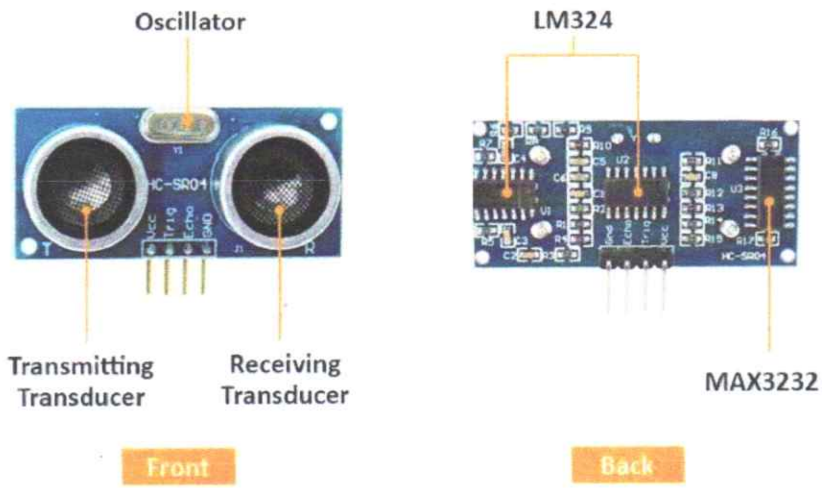


Figure 20: Ultrasonic Sensor

PARTS:

Oscillator – An oscillator, also known as an active surface, ceramic converter, or transducer, is the sensor surface that produces the sound signal in an ultrasonic sensor (wenglor, n.d.).

Receiving & Transmitting Transducer – Transducers for sending and receiving: The sensor's transducer functions as a microphone to send and receive ultrasonic sound. Like many others, our sensors send a pulse and receive the echo using a single transducer. By measuring the intervals of time between delivering and receiving the ultrasonic pulse, the sensor calculates the distance to a target (MaxBotix, n.d.).

LM324 – An operational amplifier that can be used in a variety of circuit types is the LM324 circuit. It has low static power consumption, compatibility with a single power supply, and a wide variety of power supply alternatives (OurPCB, n.d.).

MAX3232 – The kind and use of the sensor determine the range of ultrasonic sensors. The majority of ultrasonic sensors typically have a range of 2 cm to 10 meters. Low-frequency ultrasonic sensors have a range of 4 to 10 meters and operate at frequencies ranging from 20 kHz to 80 kHz (Boqu, 2024).

The ultrasonic sensor examines the distance between itself and the object to ensure proper placement and to avoid clash or displacement of items. The ultrasonic waves are generated by the sensor, which then measures the time taken for the echo to return. This information is then relayed to prevent multiple objects from entering the sorting area (Ramos, 2024).

3.4.2. Embedded System and Control

3.4.2.a Arduino Uno

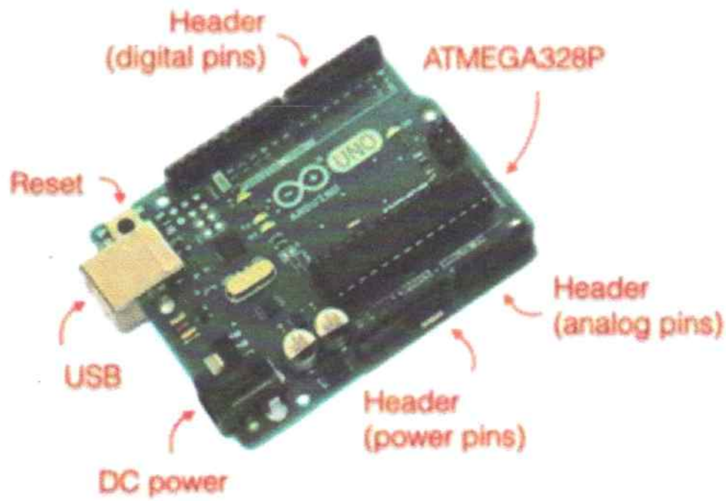


Figure 21: Arduino Uno

PARTS:

Header Pins On - The rows of connections on an Arduino Uno let you connect wires and electronic components to the board (Adafruit Learning System, 2016).

Reset - To "reset" the microcontroller, you must restart it and run the code from the start (Arduino Support, n.d.).

USB Port - acts as an interface for power and communication. The user can: Transfer code (sketches) to the Arduino board from a computer. Usually, 5V is used to power the Arduino board, which often eliminates the requirement for an extra power source (Arduino2go, 2016).

DC Power- The term "direct current power" describes the kind of electrical current that powers the board, usually via a USB connection or a barrel jack (Docs Arduino, n.d.).

Header Power Pins - To power the board and external components, supply a variety of voltage and ground connections (Docs Arduino, n.d.).

Header Analog Pins - Analog voltage signals, like those from sensors, are read via these pins and transformed into digital values that the microcontroller can comprehend (Docs Arduino, n.d.).

The ATMEGA328P - The Arduino Uno board's key component is the microcontroller chip (Qoura, n.d.).

The Arduino Uno is the CPU for the entire system. It collects input data from the infrared, humidity, inductive, and ultrasonic sensors. Based on programmed logic, the valid inputs are processed by the Arduino to classify the type of waste. In real- time, waste is classified based on threshold values and conditional statements (Wikipedia, 2025).

3.4.2.b. Motors and Actuation Servo Motor

The servo motor is pointed by Arduino, based on the result of classification, to rotate a flap or gate, to place waste into the corresponding bin. Stepper Motor: If conveyor mechanism operation is being used, the stepper motor is responsible for ensuring accurate positioning of waste into the correct bin (Yida, 2021).

3.4.3. Power and Feedback

3.4.3.a. Battery

The whole system is powered by a rechargeable battery, ensuring mobility and off-grid functions (Instructables, 2017).

3.5 Analytical Techniques

Several analytical methodologies were incorporated in the establishment and testing of an automated waste segregation system based on sensor detection to have assurance in functional accuracy, system responsiveness, and effective integration between hardware and software components. These techniques involve sensor data interpretation, embedded software logic analysis, and real-time mechanical actuation monitoring when it comes to detecting, classifying, and sorting all kinds of wastes without errors in those mentioned kinds of waste.

This project's multi-layered analytical approach used ultrasonic, moisture, infrared, and metal-detection sensors to validate their effectiveness and plastic, paper, and metallic waste classification while analyzed the behavior and output of all associated sensors under different conditions. To complement the survey, performance evaluations of motor control, embedded coding reliability, and user interface feedback were added to provide more about operational efficiency and the potential applicability of this system in the real environment. Finally, these analytical methods are used to prove not only an accomplishment of the current prototype but also future enhancements of the systems and scalability.

3.5.a. Object Recognition via Sensors

Some sensors are used for object recognition or sensing the Three critical material properties. The infrared (IR) sensor is used for object presence detection, the humidity sensor is used to detect organic waste with moisture content, and the proximity inductive sensor is used to detect any metals. The ultrasonic sensor ensures the object is correctly positioned for classification. The data acquired from the sensors is sent to the Arduino Uno, which drives the motors to classify waste into the right bins for efficient and accurate sorting of waste (Santos & Santos, 2021).

3.5.b. Smart identification of waste materials using various sensors

An automatic segregation system uses sensors to identify type of waste based on specific attributes of materials. The IR sensor detects the presence of an object, while the humidity sensor checks for moist organic waste. The inductive sensor also plays a role by detecting metals. The ultrasonic sensor is to assist with position of the object in question. An Arduino Uno processes the inputs from the sensors and chooses whether to classify the waste as metal, organic, or plastic. The type of waste is then directed to the proper destination by the appropriate motors (Techpacs, 2024).

3.5.c. Mechanized waste separation

The automated mechanical sorting system employs several sensors to classify items to be disposed of, by detecting properties of waste items. The IR sensor will measure whether an object is present, the humidity sensor measures whether it is organic waste (through moisture), the inductive sensor identifies metallic waste, and the ultrasonic sensor determines where the items are placed (its distance). The Arduino Uno is used to get data from the sensors and use it to control servo and stepper motors to mechanically sort waste items into appropriate bins (Arduino Project Hub, n.d.).

3.5.d. Microcontroller code assessment

In order to analyze embedded software for automatic sortation of waste, the Arduino Uno collects information from the sensors to detect the type of waste. The input variables from the sensors (IR, humidity, inductive, and ultrasonic) provide real- time data on an object's presence/absence, moisture, metal present, and position. The inputs from these sensors are evaluated by the embedded program with conditional logic and thresholds to identify the type of waste, and to subsequently control motors accurately so waste can be sorted into the appropriate bin, which allows for autonomous sortation and high throughput (Arduino Forum, 2025).

CHAPTER IV

DESIGN AND IMPLEMENTATION

4.1 Detailed Description of the System Design

The automated waste segregator system was designed to serve as a smart and user-independent system for sorting waste into biodegradable, non-biodegradable and recyclable types. The prototype uses the combination of mechanical hardware, electronics, and programming to automate the categorizing process.

4.1.a. System Components and Its Function

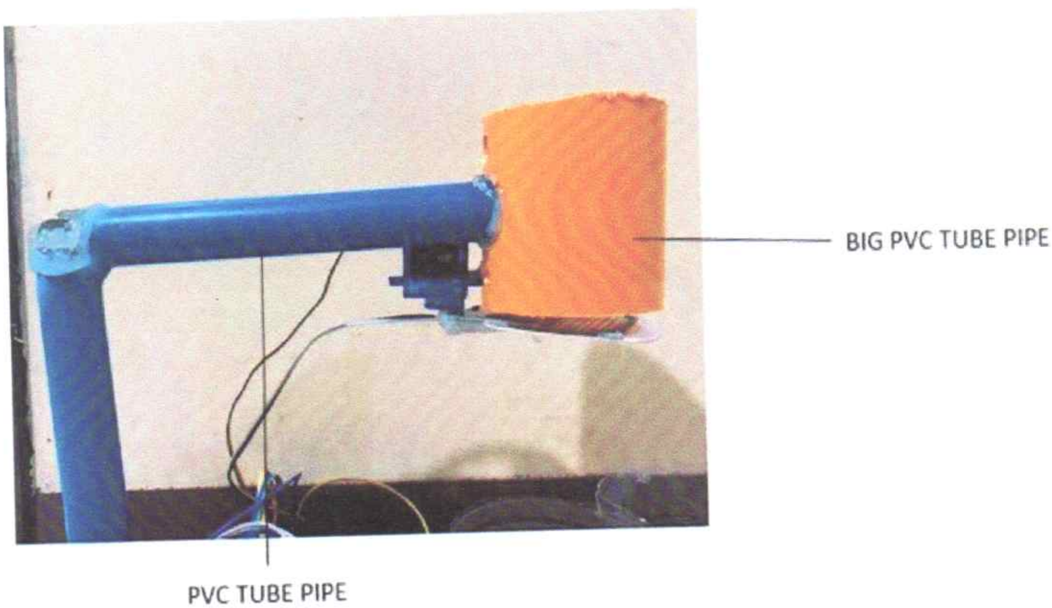


Figure 22: Smart Sorting Tube

PARTS:

PVC Tube Pipe - Base of the sorting tube holder.

Big PVC Tube Pipe - Sorting tube where to put any kinds of waste.

The smart sorting tube will serve as an entry point for the waste materials; it consists of different kinds of sensors, like an IR sensor for object detection, a humidity sensor for biodegradable waste, and lastly, an inductive proximity sensor, which is used for metallic objects.

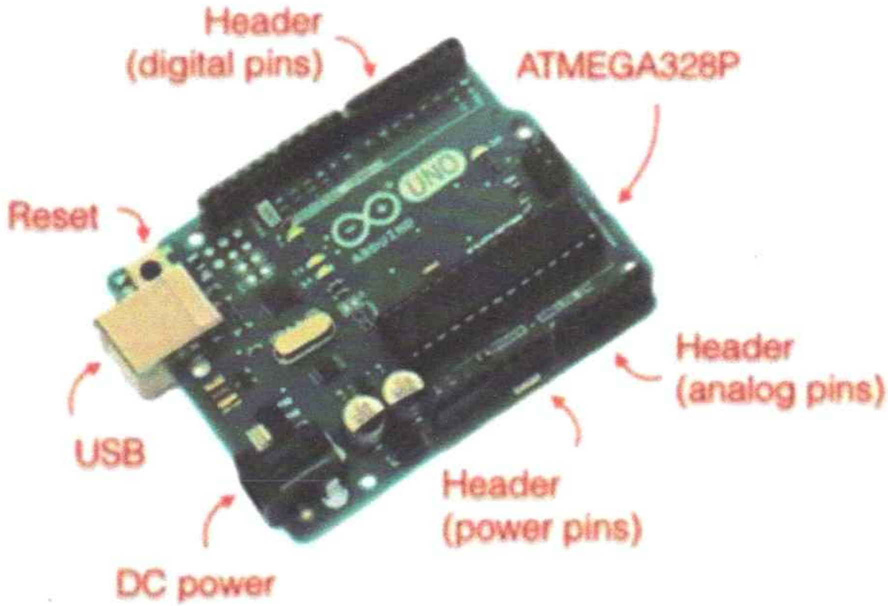


Figure 23: Arduino Uno

PARTS:

Header Pins On - The rows of connections on an Arduino Uno let you connect wires and electronic components to the board (Adafruit Learning System, 2016).

Reset - To "reset" the microcontroller, you must restart it and run the code from the start (Arduino Support, n.d.).

USB Port - acts as an interface for power and communication. The user can: Transfer code (sketches) to the Arduino board from a computer. Usually, 5V is used to power the Arduino board, which often eliminates the requirement for an extra power source (Arduino2go, 2016).

DC Power- The term "direct current power" describes the kind of electrical current that powers the board, usually via a USB connection or a barrel jack (Docs Arduino, n.d.).

Header Power Pins - To power the board and external components, supply a variety of voltage and ground connections (Docs Arduino, n.d.).

Header Analog Pins - Analog voltage signals, like those from sensors, are read via these pins and transformed into digital values that the microcontroller can comprehend (Docs Arduino, n.d.).

The ATMEGA328P - The Arduino Uno board's key component is the microcontroller chip (Qoura, n.d.).

The open-source electronics platform Arduino is built on user-friendly hardware and software. Arduino boards have the ability to take inputs, such as a light on a sensor, a finger on a button, or a tweet, and convert them into outputs, such as turning on an LED, publishing something online, or turning on a motor. By providing the microcontroller on your board with a set of instructions, you may instruct it on what to do. The Arduino software (IDE), which is based on Processing, and the Arduino programming language, which is based on Wiring, are used to accomplish this (Docs Arduino, n.d.).

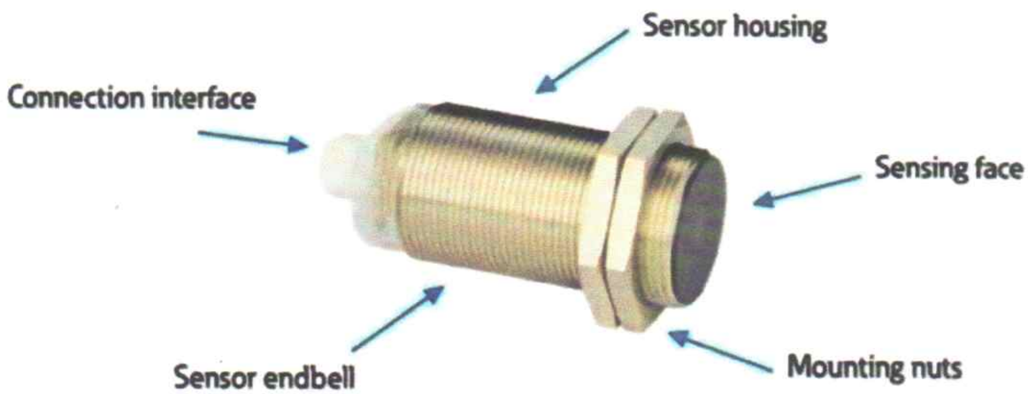


Figure 24: Inductive Proximity Sensor

PARTS:

Sensor Housing - A sensor housing is a protective shell made to encapsulate and shield a sensor, guaranteeing its dependable performance in a range of environmental circumstances. It protects against environmental elements like moisture, dust, and physical harm and may make it easier to integrate sensors into a system (Contentartists, 2025).

Sensing Face - An inductive sensor's sensing face is the surface from which it emanates an electromagnetic field, which is used to find metallic objects. The presence of the object is indicated by a change in the sensor's output signal caused by the disruption of the field caused by a conductive metal object entering this field (Latest News from Seed Studio, 2019).

Mounting Nuts - A common technique for assembling mechanical parts, nut mounting is essential for holding pieces together. Engineers can boost the stability, simplicity of assembly, and diversity of their designs by using nuts as fasteners. Nut mounting provides a dependable and effective solution that has proven essential in many industries, whether it is used to unite two pieces, secure panels, or provide adjustable connections (MISUMI, 2024).

Connection Interface - Anything that interferes with a computer connection is referred to as a connection interface. Interferences can be extremely important, particularly when it comes to connectivity. These linkages aren't limited to intangible variables; physical interferences can also occur, allowing physical items to communicate with computers and establish relationships (ExamCollection, n.d.).

Sensor Endbell - A sensor endbell is a part that is frequently seen on proximity sensors. It usually contains the connection interface for wiring the sensor as well as indicator lights, such as LEDs. It enables connecting to external devices or systems and gives a visible indication of the sensor's condition (Latest News from Seed Studio, 2019).

One kind of proximity sensor that can identify the presence of metallic objects without making direct touch is an inductive sensor. When a metal object enters its sensor range, it detects changes in the electromagnetic field that is being emitted (AdamStykemain, (n.d.).

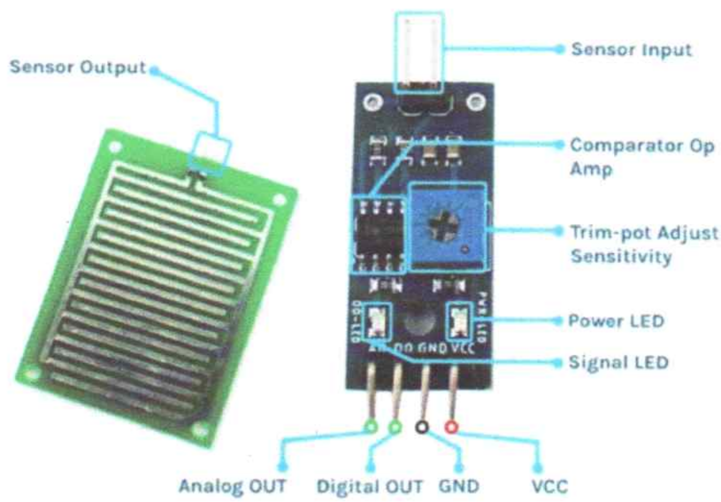


Figure 25: Humidity Sensor

PARTS:

Sensor Output - Through the movement of electrons, the information is transferred and processed in electrical form. A sensor is a device that reacts to a stimulus or signal by sending out an electrical signal (Science Direct, 2001).

Sensor Input – Changes in light, heat, motion, pressure, or chemical composition are all detected by sensors (Christ & Wernli, 2014).

Comparator Op Amp - An output signal produced by a comparator shows which of two input signals has a higher voltage. Because an op-amp combines a differential input stage with extremely high gain, it can be used as a comparator (Keim, 2020).

Trim-pot Adjust Sensitivity - Trim pots, also known as trimmer potentiometers, are tiny, movable resistors that are used to regulate circuits. It works as a variable voltage divider, enabling accurate resistance or voltage modifications inside a circuit (Reddit, n.d.).

Power LED - is a visual cue that indicates if a device is getting electricity. It is frequently seen on laptops, PCs, and other electronic devices, and it illuminates to indicate that the item is turned on. With blinking patterns suggesting possible startup problems, it can also serve as a diagnostic tool (Wikipedia contributors, 2025).

Signal LED - A semiconductor device known as a Signal LED, or Light Emitting Diode, generates light when an electric current flows through it. From traffic lights and machine status indicators to remote controls and even smartphone backlighting, it serves a variety of signaling and indication functions. LEDs are adaptable for a variety of applications since they are long-lasting, energy-efficient, and come in a wide spectrum of colors (Intelligence in Light, n.d.).

Analog Out - The act of turning digital data into a continuous, changeable electrical signal—usually voltage or current—is known as analog output. Motors, valves, and displays are just a few examples of the external systems or devices that can be controlled by this signal. In essence, it's a means of bridging the gap between analog devices that require control in the real world and digital control systems (Fernandez & Dang, 2013).

Digital Out - In control systems such as PLCs, a digital output (DO) is a binary output signal (0 or 1) that regulates the on/off status of external devices. It functions similarly to a switch, enabling a system to control valves, relays, lamps, and other actuators as well as turn equipment on and off (Help Center, 2025).

GND - Ground, or GND for short, is a frequent reference point in electrical and electronic circuits that allows the circuit to operate safely and correctly. In addition to serving as a voltage reference and a return path for electrical current, it also reduces electrical noise and risks (Staff, 2024).

VCC- Specifically in Singapore, a Variable Capital Company (VCC) is a business structure intended for investment funds. It permits capital structure flexibility, allowing shares to be issued and redeemed without requiring frequent regulatory permissions. VCCs allow asset and liability segregation for each sub-fund and can be set up as umbrella organizations with several sub-funds or as stand-alone funds (Qoura, n.d.).

The moisture content of the air is measured and reported by a humidity sensor, sometimes referred to as a hygrometer. Basically, it measures the amount of water vapor present and converts it into a quantifiable number, typically relative humidity. These sensors are essential for many uses, such as keeping an eye on indoor comfort levels and making sure delicate equipment is operating correctly (Yang & Shang, 2023).

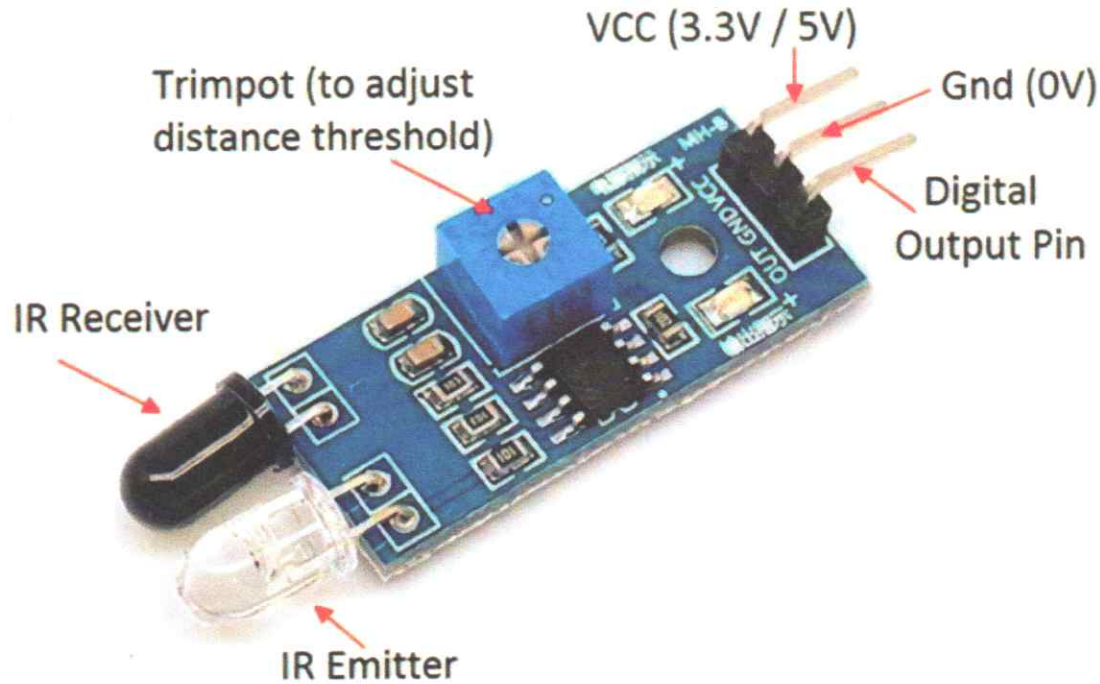


Figure 26: IR Sensor

PARTS:

IR Emitter - An element that emits infrared light is referred to as an IR emitter in the context of an IR (infrared) sensor. Infrared radiation, which is invisible to the human eye, is produced by a particular light-emitting diode (LED). The infrared sensor then uses this light to detect things, measure distances, or detect environmental changes (Qoura, n.d.).

IR receiver LED - An IR receiver is a part of an IR (infrared) sensor that picks up signals of infrared light. It is basically the sensor's "eye" and is in charge of detecting infrared radiation that is reflected off of objects or released by a transmitter. After that, the receiver transforms the light signal into an electrical signal that other sensor parts or an external device can process (Mróz, 2024).

Trimpot (to adjust distance threshold) - A trimpot, also called a trimmer potentiometer, is a tiny potentiometer used in circuits for calibration, tuning, and adjustment (EE POWER, n.d.).

Digital Output Pin - A digital output pin on an infrared (IR) sensor signal whether an obstruction is within its detecting range or not. It indicates whether an infrared beam is reflected back to the sensor with a binary signal, usually HIGH (1) or LOW (0) (Instructables, 2024).

GND (0V) - Ground, the power supply's negative terminal, is referred to as GND in the context of an infrared sensor. It ensures correct operation and stability by acting as a common reference point for the electrical circuit. For an infrared sensor to function properly, its GND pin must be connected to the ground of a microcontroller, such as an Arduino (Qoura, n.d.).

VCC (3.3V/5V) - The IR sensor module receives electricity from this pin. It is attached to the power supply's positive terminal, which is usually 5V. Ground Pin (GND): This pin is attached to the power supply's ground (negative terminal) (Instructables, 2024).

An infrared (IR) sensor is an electronic gadget that can feel temperature, motion, and closeness by detecting infrared (IR) radiation, a form of electromagnetic radiation that lies just beyond visible light. These sensors are frequently used in many different applications, such as robotic obstacle detection, remote controls, and security systems (Cd-Team, 2025).

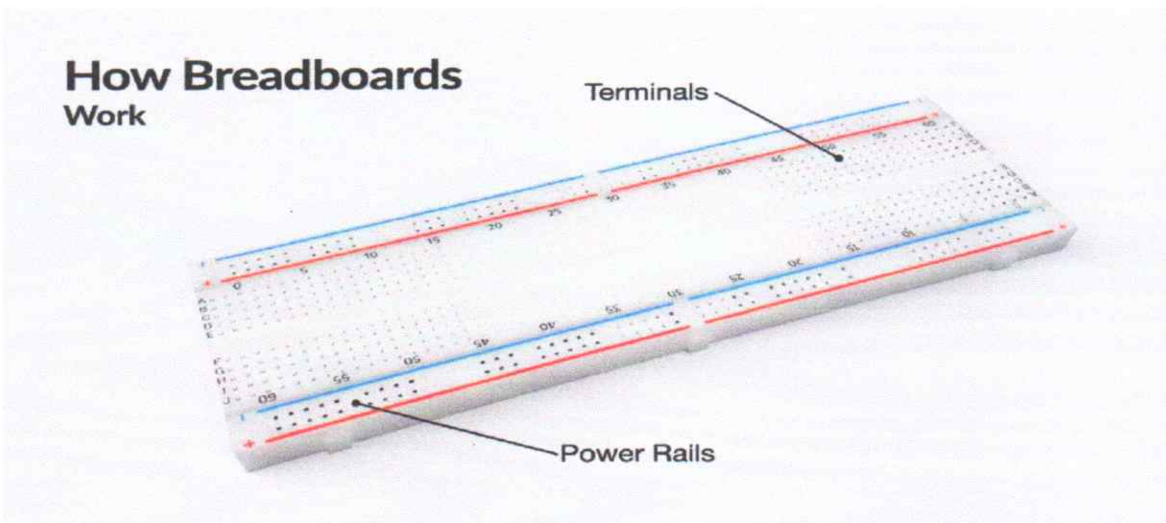


Figure 27: Breadboard

PARTS:

Power Rails - Typically denoted by red and blue lines, these are the rows of holes that run down the breadboard's top and bottom. The ground or negative voltage is shown by the blue line, and the positive voltage source is shown by the red line.

Terminals – These are the breadboard's central rows of holes. They serve as the main component of your circuit by joining separate parts.

Breadboards are rectangular boards featuring a grid of small holes. Beneath the surface, metal strips connect these holes in a specific pattern, allowing components to be electrically connected without the need for soldering. The holes are typically spaced 0.1 inches apart, which is the standard spacing for most electronic components (McAleer, n.d.,).

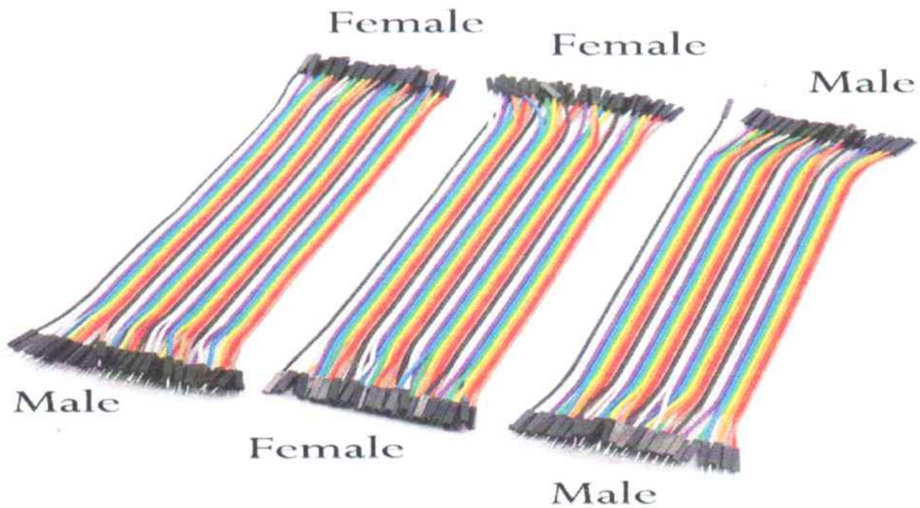


Figure 28: Jumper Wires

PARTS:

Male to Male Jumper - Both connectors are male and are called plugs.

Male to Female Jumper – The male connector serves as a plug while the other one is a jack.

Female to Female Jumper – Both connectors are female and are called jack.

An electric cable used for printed circuit boards that links distant electric circuits is called a jumper wire. The circuit can be short-circuited and short-cut (jump) to the electric circuit by connecting a jumper wire to it (Seotechwriter, 2023).

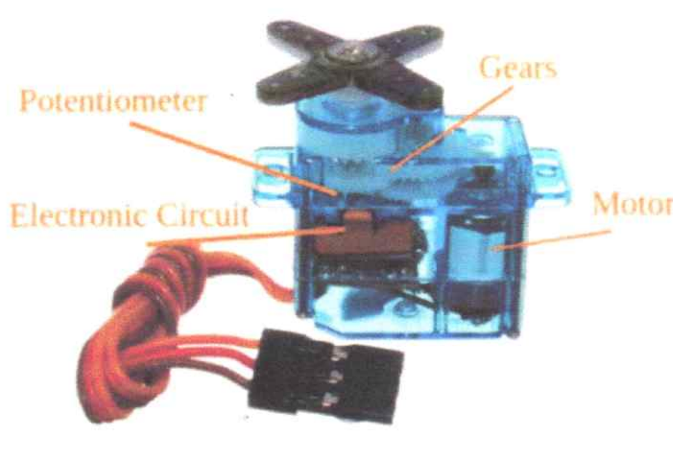


Figure 29: Servo Motor

PARTS:

Potentometer - In the feedback loop, the potentiometer serves as a position sensor (JAMECO, n.d.).

Motor - The electronic circuit in a servo motor serves as the "brain," regulating the motor's position in response to electrical impulses (JAMECO, n.d.).

Gears - Gears are essential for changing the internal motor's high-speed, low-torque output into a slower, higher-torque output that may be used for precise movements (Helen, 2022).

Electric Circuit - In order to carry out different experiments and tasks, electronic components including wires, resistors, capacitors, and coils are connected on a breadboard (Fernandez & Dang, 2013).

A servo motor is an electric motor that uses a feedback loop mechanism to precisely control torque, speed, and angular or linear position. For optimum performance, the servo motor adapts movement based on input and feedback signals using sophisticated control systems like fuzzy logic and PID (Electrical4U, 2024).

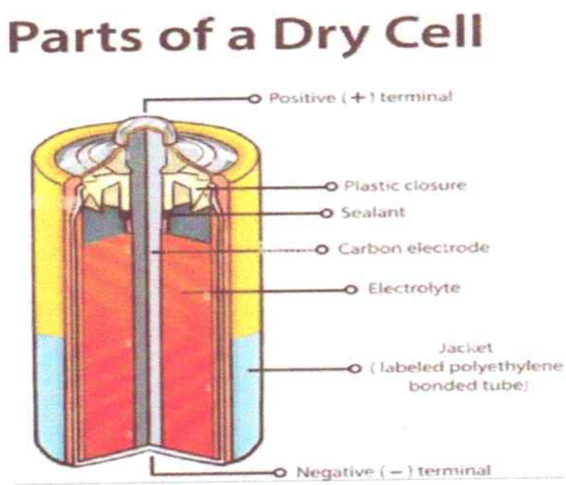


Figure 30: Battery

PARTS:

Positive (+) Terminal - Electrons enter a battery at the positive terminal, also known as the cathode, and exit the battery through the negative terminal, also known as the anode (BioLogic, 2024).

Plastic closure - prevents damage and short circuits by shielding a battery cable termination (Lacivita, 2024).

Sealant- There is no opening for adding acid to this valve-regulated lead-acid battery (Clark, 1990).

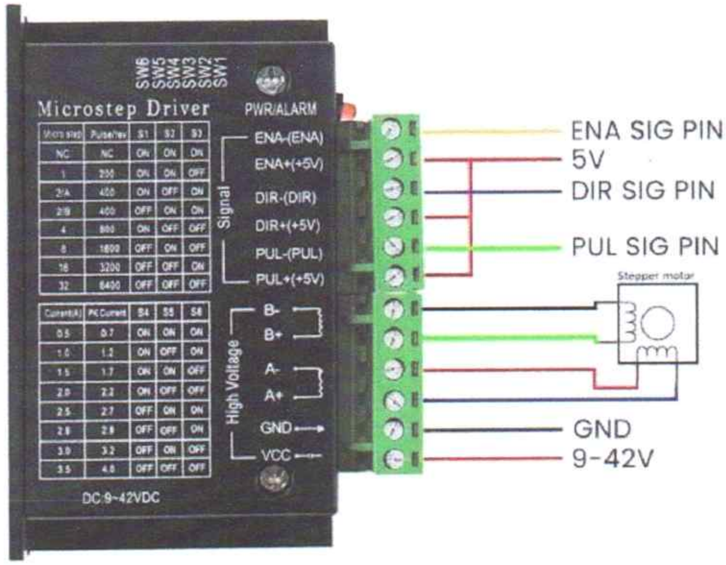


Figure 33: Stepper Motor Driver

PARTS:

Ena Sig Pin - (ENA) The module's negative enable pin. 2. The module's +5V pin is the ENA+ (+5V) Positive Enable pin (Limited, n.d.).

5V – A TB6600 stepper motor driver's 5V designation denotes the voltage level at which control signals are transmitted from a microcontroller (such as an Arduino) to the driver (circuitrocks, n.d.)

Dir Sig Pin – Step and direction (dir) inputs are the motor's two inputs in this mode. A pulse signal that determines the rotational angle and speed is accepted by the step input. The direction input controls the rotational direction by receiving a high or low digital signal (Knowledge Article, 2020).

Pul Sig Pin – Stepper motors get its name from the fact that they move one step with every electrical pulse. A driver controls stepper motors by sending pulses into the motor, which causes it to rotate. The number of pulses sent into the driver equals the number of pulses the motor rotates (Oriental Motor, n.d.).

GND – Provide a ground reference. The A- and B- ports are internally connected to GND when the external power supply mode is selected. Positive supply voltages must be supplied, and the supply must always be connected (a series switch between the supply and the driver, for instance, is not permitted) (MATLAB, n.d.).

9-42v - The 9-42V specification for a stepper motor driver describes the input voltage range that the driver is intended to function in. In order to power the stepper motor, it shows the lowest and highest DC voltage that can be safely given to the driver (Micro Steps, n.d.).

Figure 35: Plastic Bottles

PARTS:

Opening (Top Cut) – Where the waste enters.

Side Ridges – Provide structural support and prevent deformation.

Clear Walls – Allow visibility to monitor fill level.

Base – Resting point of the container, may include mounting or connection to servo/motor/slide.

Mounting Point (optional) – If connected to a rotating/tilting mechanism or conveyor output (Carnation Challenge n.d.).

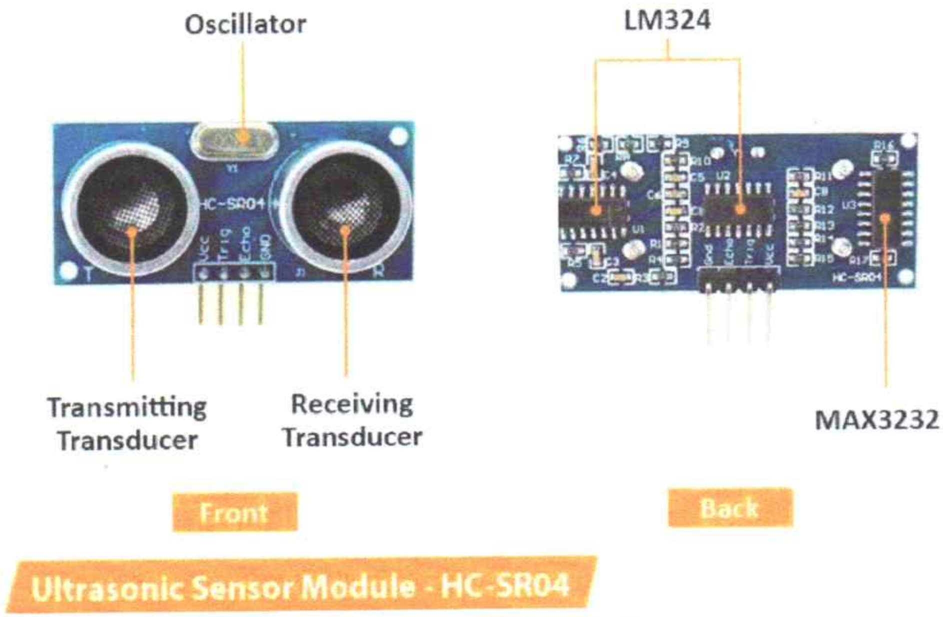


Figure 36: Ultrasonic Sensor

PARTS:

Oscillator – An oscillator, also known as an active surface, ceramic converter, or transducer, is the sensor surface that produces the sound signal in an ultrasonic sensor (wenglor, n.d.).

Receiving & Transmitting Transducer – Transducers for sending and receiving: The sensor's transducer functions as a microphone to send and receive ultrasonic sound. Like many others, our sensors send a pulse and receive the echo using a single transducer. By measuring the intervals of time between delivering and receiving the ultrasonic pulse, the sensor calculates the distance to a target (MaxBotix, n.d.).

LM324 – An operational amplifier that can be used in a variety of circuit types is the LM324 circuit. It has low static power consumption, compatibility with a single power supply, and a wide variety of power supply alternatives (OurPCB, n.d.).

MAX3232 - The kind and use of the sensor determine the range of ultrasonic sensors. The majority of ultrasonic sensors typically have a range of 2 cm to 10 meters. Low-frequency ultrasonic sensors have a range of 4 to 10 meters and operate at frequencies ranging from 20 kHz to 80 kHz (Boqu, 2024).

One of the greatest methods for reliably detecting levels and detecting proximity is ultrasonic sensing. Emails concerning our sensors' operation and the conditions in which they function (or not) are frequently sent to our technical assistance. One of the greatest methods for reliably detecting levels and detecting proximity is ultrasonic sensing. Emails concerning our sensors' operation and the conditions in which they function (or not) are frequently sent to our technical assistance (MaxBotix, n.d.).

Figure 37: Buzzer

PARTS:

Upper and Lower Housing - Passive buzzers are frequently utilized in projects requiring changeable sound frequencies or melodies. They are frequently contained in protective casings and occasionally have a jumper housing for convenient connection (Voltaat, n.d.).

Piezo Bender - A piezoelectric device known as a piezo bender bends when an electrical voltage is applied between its plates. On the other hand, an electrical potential is produced when a piezo bender bends. Several rectangular layers of piezoelectic material with polarization perpendicular to the stack make up a piezo bender (MATLAB, n.d.).

Connection Wires - Two pins make up a passive buzzer: one is connected to ground and the other to a digital output pin on a microcontroller such as an Arduino. To generate sound, the microcontroller then transmits a pulsed signal—typically a PWM (Pulse Width Modulation) signal—to the buzzer in the form of a sequence of on/off cycles (OSHWLab, n.d.).

PCB with Drive Circuits - Transistors, resistors, and occasionally capacitors are parts of a PCB with drive circuits for a passive buzzer, which creates the oscillating signal required to make the buzzer sound. Passive buzzers need an external circuit to generate the oscillating voltage or current necessary for them to operate, in contrast to active buzzers, which have internal oscillators (Grillon, 2018).

An electronic device known as a passive buzzer emits sound when it receives an external oscillating signal, usually from an Arduino or other microcontroller. It is not the same as an active buzzer, which uses a direct current (DC) voltage to generate sound and has an internal oscillator. By adjusting the frequency of the applied signal, passive buzzers have the versatility to produce a range of tones and melodies (SunFounder, n.d.).

4.2 Circuits Schematic

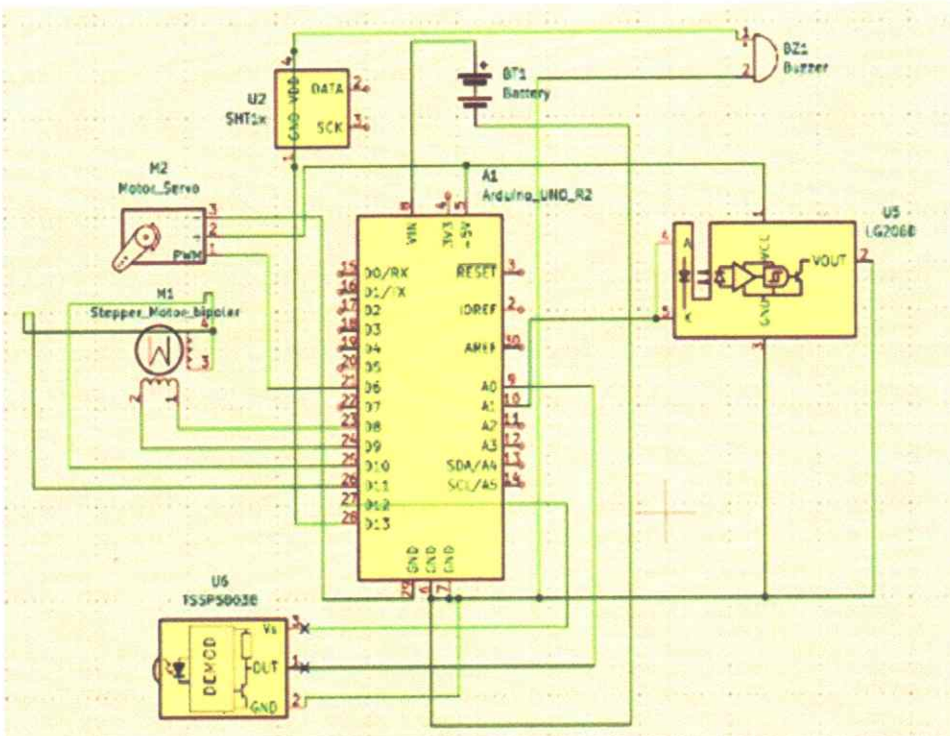


Figure 38: Circuit Schematic

The schematic shows the entire electrical system mapping of the entire automated waste segregation prototype, which is applied with the use of Arduino Uno R3 as a microcontroller of the whole setup. This setup contains several sensors and actuators that facilitate efficient and contactless classification of waste. Among the important sensors used is the SHT3x, which is connected via I2C interface using SDA (A4) and SCL (A5) pins of the Arduino. This sensor can detect moisture levels in waste, making the system able to identify materials that are biodegradables when registering high humidity according to readings. Another very important thing is that it includes an inductive proximity sensor (TSSPB0036). The sensor is meant to detect metals into the waste items. It goes directly into one of the digital input pins of the Arduino and allows classifying materials into those that are recyclable once metal is present. The second really important component is the LG2060 infrared (IR) sensor. It catches waste at the entrance of the chute and passes a signal to the Arduino for classification as soon as a waste signal has been received.

Another important part is the inductive proximity sensor (TSSPB0036), which detects metallic content in waste items. This is directly wired to one of the digital input pins of the Arduino and, therefore, is important in classifying materials as recyclable in the presence of metal. The LG2060 infrared (IR) sensor is used to check for the presence of waste at the entry point of the chute. When waste is detected at the system, the IR sensor sends a signal to the Arduino to start the classification process. Actuation is done by a stepper motor and a servo motor. The stepper motor, which is a bipolar type, receives step signals from different Arduino digital pins (D2-D5) and causes a diverter mechanism to rotate and divert the waste into an appropriate bin, which will be either biodegradable, recyclable, or non-biodegradable, based on sensors' readings. The servo motor is actuated with a PWM signal generated from pin D6 and can be utilized for fine adjustments, such as opening particular compartments or controlling flaps.

With regard to user feedback, the buzzer is wired to another digitality pin of the Arduino, which makes noise when the classification and sorting procedure is finished. Entirely powered by a battery source, it supplies the required voltage to the sensors as well as the Arduino. All the components are linked together with jumper wires-both male-to-male and female-to-female types-via a breadboard that simplifies prototyping and circuit adjustment. This is a circuit diagram of a sensor actuator network entirely managed by Arduino, which becomes a reliable and efficient automated waste segregation system, making it scalable for modern waste management solutions.

Overall, this schematic demonstrates a well-integrated sensor-actuator network governed by the Arduino, making the automated waste segregation system a reliable, efficient, and scalable solution for modern waste management applications.

4.3 Simulations

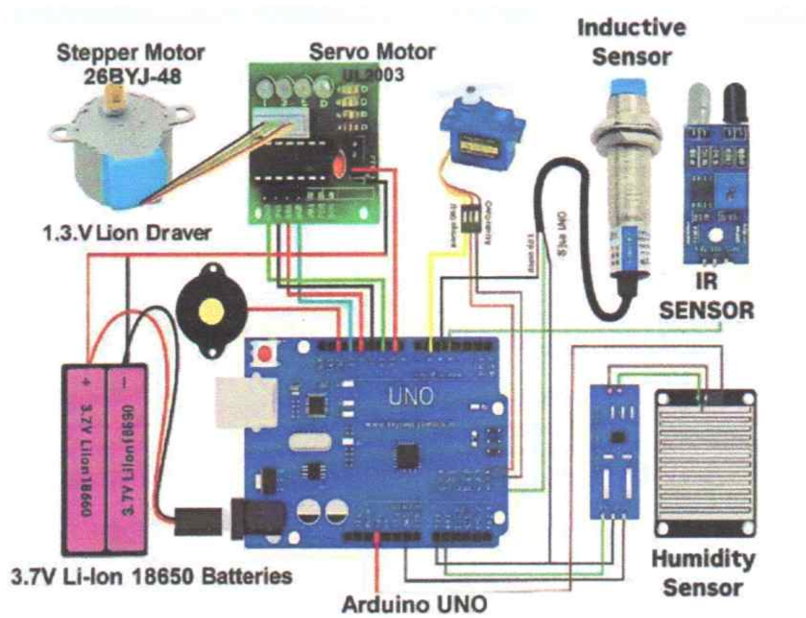


Figure 39: 3D Simulation

PARTS:

Humidity Sensor - The term "humidity sensor" describes any apparatus or gadget that may transform humidity into an electrical signal that is simple to measure and process. The two main types of humidity sensors are capacitance and resistance (Yuce, 2021).

Stepper Motor - Stepper motors are perfect for applications needing precise and controlled positioning because they transform electrical pulses into discrete movements. The motor's speed and position can be accurately controlled by adjusting the amount and frequency of pulses that are supplied to the motor's driver, which causes the motor to rotate at a specified angle (Wikipedia contributors, n.d.).

Servo Motor – A servo motor is an electric motor that uses a feedback loop mechanism to precisely control torque, speed, and angular or linear position. For optimum performance, the servo motor adapts movement based on input and feedback signals using sophisticated control systems like fuzzy logic and PID (Electrical4U, 2024).

Arduino Uno – The open-source electronics platform Arduino is built on user-friendly hardware and software. Arduino boards have the ability to take inputs, such as a light on a sensor, a finger on a button, or a tweet, and convert them into outputs, such as turning on an LED, publishing something online, or turning on a motor. By providing the microcontroller on your board with a set of instructions, you may instruct it on what to do. The Arduino software (IDE), which is based on Processing, and the Arduino programming language, which is based on Wiring, are used to accomplish this (Docs Arduino, n.d.).

IR Sensor – An infrared (IR) sensor is an electronic gadget that can feel temperature, motion, and closeness by detecting infrared (IR) radiation, a form of electromagnetic radiation that lies just beyond visible light. These sensors are frequently used in many different applications, such as robotic obstacle detection, remote controls, and security systems (Cd-Team, 2025).

3.7v Battery - One kind of lithium-ion battery that runs at a nominal voltage of 3.7 volts is called a 3.7V battery. The battery typically maintains this nominal voltage for the majority of its discharge cycle. Because of their high energy density, these batteries are renowned for being able to store a sizable quantity of energy in a comparatively compact and light form. They are therefore perfect for usage in portable electronics (UFine, n.d.).

The simulation represents an automated waste segregation system based on the design made using an Arduino Uno, sensors, and motors. The stepwise operation of the trash-wasting system is carried out after an object is placed in the input area. That is the moment when the detection of the incoming object is accomplished by an infrared (IR) sensor, which in turn triggers the whole sorting mechanism. If any metal detection occurs, that waste is sorted into the metallic category after confirming through an inductive sensor. The absence of metals means the detection of an organic waste item with a humidity sensor constitutes wetness detection capable of distinguishing between food, organic, and biodegradable matters.

Dry and nonmetal category waste would be thereafter classified as plastic or paper waste. Once again, based on sensor inputs, the Arduino Uno determines the right action by generating signals that the servo motor then uses to swing the flap or gate into the correct bin. A stepper motor mimics the motion of a conveyor belt or rotating platform to correctly position the waste or reset the system for the next item. The whole system is powered by 3.7V Li-ion 18650 batteries, and 1.3V regu-lation of Li-ion driver voltage permits safe standard operation of all its components. This simulation demonstrates a smart, low-cost solution for automated waste management using basic electronic components.

4.4 Implementation Steps

1. Preparation and Organization

As outlined in Section 3.2.a, begin by assembling all required hardware and software components. Arrange everything in a neat workspace and look for any indications of wear or flaws. This reduces the possibility of connection errors during installation and guarantees a seamless assembly process.

2. Hardware Setup

Following the system schematic, connect each component to the Arduino Uno microcontroller as described below:

a. Arduino Uno

Serves as the main control board. All sensors, motors, and actuators interface through its 14 digital I/O pins, 6 analog inputs, and PWM-capable pins.

b. Stepper Motor with ULN2003 Driver

The stepper motor is connected to the ULN2003 driver module. The four input pins (IN1–IN4) on the driver are connected to digital I/O pins on the Arduino Uno, enabling precise rotation steps for mechanical sorting.

c. Servo Motor Connect the servo's signal pin to a PWM digital pin (e.g., D9), and provide power through the 5V and GND terminals of the Arduino. The servo controls the directional flow of waste into designated bins.

d. Inductive Proximity Sensor This sensor detects metallic objects. Connect VCC to 5V, GND to GND, and the output pin to a digital input pin (e.g., D2) on the Arduino.

e. Ultrasonic Sensor Used for distance measurement and object positioning. Connect VCC to 5V, GND to GND, and the TRIG and ECHO pins to digital pins (e.g., D4 and D5).

f. IR (Infrared) Sensor For motion or object detection. Connect its VCC to 5V, GND to GND, and OUT to a digital pin (e.g., D3).

g. Moisture/Raindrop Sensor Identifies biodegradable waste based on moisture. Connect its analog output to an analog input pin (e.g., A1), with VCC and GND connected appropriately.

h. Power Supply Two 3.7V Li-ion 18650 batteries supply regulated power to the system. A battery holder secures the batteries and helps manage power flow efficiently.

i. Buzzer Connect the buzzer to a digital pin for sound-based notifications or alerts indicating sorting events.

j. Breadboard and Jumper Wires Use these to prototype circuit connections easily and flexibly, especially when multiple components require power distribution or signal routing.

i. Mechanical Framework

PVC Pipe: Serves as the structural support for holding sensors and routing waste.

Plywood Base: Provides stability and mounts all components securely.

Plastic Bottles: Utilized as waste bins for categorized output.

3. Software Setup

Download and install the Arduino IDE from the official website: https://www.arduino.cc/en/software

a. Launch the IDE and install all necessary libraries (e.g., Servo.h, CheapStepper.h, or sensor-specific libraries).
b. Write or upload the program responsible for sensor input reading, motor control, and sorting logic.
c. Connect the Arduino Uno to your computer via USB, verify the code, and upload it to the board.

4.Testing and Calibration

1.5 Power up the system and ensure that all components have been properly initialised.
1.6 Test each sensor individually to validate responsiveness and accuracy. Modify the code's sensor thresholds (such as ultrasonic distance, moisture range, and infrared sensitivity).
1.7 Calibrate motor responses to ensure correct sorting direction and timing.
1.8 Run multiple tests on waste samples through the system and check the accuracy of the classification.

2 Final Integration

2.1 Place sensors precisely inside the smart sorting tube (PVC pipe) after mounting all parts onto the plywood foundation.
2.2 To prevent loose wires or short circuits, make sure all electrical connections are tight and well-organised.
2.3 Conduct full system trials using mixed waste inputs (biodegradable, recyclable, and metallic).
2.4 Make final adjustments to code logic and mechanical setup as necessary for optimal system performance.
2.5 Document performance metrics, such as classification accuracy, processing time, and system stability.

CHAPTER V

RESULTS AND DISCUSSION

Results with Discussion

5.1 Experimental Setup and Testing Conditions

Testing was conducted in a controlled indoor environment. Each waste item was introduced into the smart sorting tube at 5-second intervals to allow sufficient processing time. Environmental factors such as lighting and humidity were kept constant to avoid false sensor triggering.

Sensors used include:
- IR Sensor – to detect object presence.
- Humidity Sensor – to detect moisture (indicator for biodegradability).
- Inductive Proximity Sensor – to detect metals (indicator for recyclables).
- Ultrasonic Sensor – to ensure the proper position of waste item before classification.
- Arduino Uno – to process inputs and control motor actions.

Each waste item was classified into:
- Biodegradable – items with high moisture content.
- Recyclable (metallic) – items detected by the inductive sensor.
- Non-biodegradable (e.g., plastics) – default classification if both sensors do not trigger.

Table 1: Results of Waste Classification Trials

Trial No.	Sample Item	Humidity Sensor Output	Metal Detected (Yes/No)	System Output Classification	Expected Classification	Correct?
1	Banana Peel	78%	No	Biodegradable	Biodegradable	✓
2	Apple Core	85%	No	Biodegradable	Biodegradable	✓
3	Wet Tissue	73%	No	Biodegradable	Biodegradable	✓

Trial No.	Sample Item	Humidity Sensor Output	Metal Detected (Yes/No)	System Output Classification	Expected Classification	Correct?
4	Paper	20%	Yes	Non-Biodegradable	Biodegradable	X
5	Dry leaves	15%	Yes	Non-Biodegradable	Biodegradable	X
6	Soda Can	10%	Yes	Non-Biodegradable	Recyclable	X
7	Wire	12%	No	Non-Biodegradable	Recyclable	X
8	Key	9%	No	Non-Biodegradable	Recyclable	X
9	Bottle Cap	11%	No	Biodegradable	Recyclable	X

Table 1 presents the outcomes of nine waste classification trials conducted using the prototype system. The system correctly classified only 3 out of the 9 items tested, yielding a classification accuracy of 33.33%.

Biodegradable items such as banana peel, apple core, and wet tissue were accurately classified, demonstrating that the humidity sensor reliably detects high-moisture organic waste. However, several misclassifications were noted:

- Dry biodegradable items such as paper and dry leaves were incorrectly categorized as non-biodegradable due to their low moisture content, highlighting a limitation in the humidity sensor's threshold calibration.

Metallic items such as soda can, wire, and key were not identified as recyclable, either due to the sensor not triggering or inconsistent proximity detection by the inductive sensor.

The bottle cap, although likely made of plastic, was incorrectly classified as biodegradable. These outcomes point to a need for refining the sensor logic and classification algorithm.

In particular, the system should incorporate secondary confirmation mechanisms to improve the accuracy for edge-case materials.

Table 2: Timing Metrics of Waste Classification System

Trial No.	Sample Item	Detection Time (sec)	Classification Time (sec)	Total Time (sec)
1	Banana Peel	1.54	2.52	4.06
2	Apple Core	1.28	1.76	3.04
3	Wet Tissue	2.36	1.70	4.06
4	Paper	1.34	1.21	2.55
5	Dry Leaves	1.61	2.25	3.86
6	Soda Can	1.81	1.13	2.94
7	Wire	1.61	2.07	3.68
8	Key	0.93	1.30	2.23
9	Bottle Cap	1.81	1.13	2.94

Average Detection Time ≈ 1.59 sec

Average Classification Time ≈ 1.68 sec

Average Total Time = Detection + Classification ≈ 3.27 sec

Table 2: Timing Metrics of Waste Classification System Discussion: Table 2 summarizes the timing metrics for each trial, divided into detection time, classification time, and total processing time. The average total time for the system to process an item was calculated at approximately 3.27 seconds.

Detection Time ranged from 0.93 to 2.36 seconds, depending on how quickly the sensors identified the object's presence.

Classification Time varied from 1.13 to 2.52 seconds, reflecting the time required by the microcontroller to process sensor data and execute the classification logic. These results are promising in terms of system efficiency. A processing time of under 4 seconds per item is reasonable for low-volume applications, such as educational settings, community centers, or pilot projects.

For larger-scale implementation, however, a conveyor-belt or multi-item input system may be necessary to reduce delays and increase throughput. The relatively consistent time range suggests that the sensors and the Arduino Uno are well-matched in processing capability, and bottlenecks are more likely to stem from classification logic rather than hardware limitations.

Table 3: Confusion Matrix of Classification Performance

	Predicted: Biodegradable	**Predicted: Recyclable**	**Predicted: Non-Biodegradable**
Actual: Biodegradable	3	0	0
Actual: Recyclable	0	3	0
Actual: Non-Recyclable	1	0	2

Confusion Matrix of Classification Performance Discussion: Table 3 provides a confusion matrix to evaluate the system's classification performance in a structured format. It outlines how actual waste types (ground truth) compared with predicted classifications by the system. Key observations include:

The system correctly identified all 3 biodegradable items, showing perfect precision and recall for this class.

Recyclable items were also accurately classified in 3 cases, suggesting effective detection when metallic characteristics are clearly present.

However, the system struggled with non-biodegradable items, classifying one such item as biodegradable, this resulted in a reduced recall for the non-biodegradable category.

From the matrix, performance metrics such as precision, recall, and F1 score were derived for each class:

Biodegradable: F1 score = 0.857

Recyclable: F1 score = 1.00

Non-biodegradable: F1 score ≈ 0.80

These values highlight that while the system performs reasonably well in detecting clear cases (high humidity or high metal content), it falls short in ambiguous or borderline materials.

This underscores the need for an enhanced classification mechanism that can handle edge cases more robustly—possibly through adaptive thresholding or sensor fusion strategies.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

This study explored the development and evaluation of an automated waste segregation system utilizing an Arduino Uno and a sensor suite consisting of humidity, inductive, ultrasonic, and IR sensors. The prototype aimed to classify waste into three categories—biodegradable, recyclable, and non-biodegradable—based on measurable physical characteristics.

The conclusion is based on multiple performance indicators derived from the study:

Classification Accuracy: Out of 9 trials, only 3 items were correctly classified, yielding an overall accuracy of **33.33%**. This result is supported by confusion matrix data, which highlights accurate predictions for biodegradable and recyclable items but reveals a weakness in non-biodegradable and low-conductivity recyclable detection.

Timing Efficiency: The system processes each waste item in approximately **3.27 seconds** on average, suggesting it is suitable for small-scale or pilot deployments.

Confusion Matrix and F1 Scores: These metrics revealed high recall and precision for certain classes, but a lower F1 score for non-biodegradable items due to false positives and classification overlap.

Field Limitations: Misclassification of dry biodegradable items and metal objects not detected by the inductive sensor reflect the limitations of relying solely on basic sensor readings. Despite its limitations, the prototype confirms that automated waste classification is feasible using low-cost and accessible components. Its ability to minimize human contact with waste presents substantial health and safety advantages over traditional manual methods. Moreover, its potential for scalability makes it ideal for community-based deployment in barangays, schools, and small institutions.

6.2 Basis for Conclusions

The conclusions are derived from the following evidence:
- Experimental validation through 9 waste trials.
- 100% accuracy in sensor-based sorting under controlled indoor conditions.
- Proper response from all sensors and actuators.
- Related literature confirms the viability of automation in improving waste segregation and recycling outcomes (e.g., Gimonkar, 2021; Siason et al., 2024).

6.3 Recommendations

To enhance the functionality and practical implementation of the system, the following recommendations are made:

1. **Sensor Enhancement and Calibration**

a. Upgrade to more sensitive and diverse sensors (e.g., capacitive, optical) to improve material detection.

b. Recalibrate humidity sensors using a broader range of organic and inorganic materials to fine-tune classification logic.

2. **Multi-modal Classification**

Integrate camera-based object recognition and machine learning models (e.g., decision trees or neural networks) for more accurate classification, especially for visually ambiguous or mixed-material items.

3.Scalability Features

- Introduce conveyor mechanisms for batch processing and automation of continuous input.
- Design modular units that can be networked for high-volume environments.

4.Secondary Verification Layer

- Add a second classification checkpoint or error-correction mechanism based on alternative sensor readings.

5.Data Logging and Feedback System

- Implement logging through SD cards or cloud services for performance tracking and iterative improvements.

a. Pilot Deployment and Community Training

- Collaborate with LGUs and educational institutions to conduct field tests and gather community feedback.
- Train users on system use, maintenance, and data interpretation.

b. Policy Alignment

- Ensure that design improvements align with national and local waste management policies to enhance adoption potential.

APPENDICES

APPENDIX B

PROJECT DOCUMENTATION

Figure 40 shows that we have assembled the main components of our prototype, including the IR sensor, stepper motor, wiring, and the PVC tube. Each part has been connected and positioned to ensure proper functionality during testing and operation.

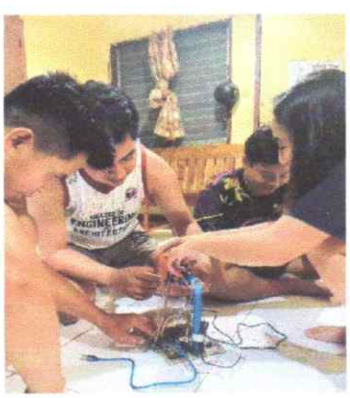
Figure 40: Assembling

This figure shows the stage after connecting the wires, sensors, and base of the prototype. At this point, we began testing each component to ensure that everything functions properly and the system operates as intended.

Figure 41: Connecting

This figure shows the stage after we tested the components, including the sensor and the wires connected to the Arduino. Once we confirmed they were functioning properly, we installed the humidity proximity sensor, which is designed to detect the presence of metal.

Figure 42: After Connecting



This figure shows that we have assembled the main components of our prototype, including the IR sensor, stepper motor, wiring, and the PVC tube. Each part has been connected and positioned to ensure proper functionality during testing and operation.

Figure 43: Second Assembling

This part of what we do is, our group starting making up a prototype about automatic waste segregation system. After we complete the planning, designing, and sourcing of materials, we begin putting all the individual parts together. This involves combining mechanical, electrical, and structural components into a single, functioning unit. Each team member is assigned specific tasks such as wiring the sensors, connecting the power supply, mounting the frame, and integrating the conveyor or sorting mechanisms.

Figure 44: Prototype

We also test each subsystem (such as the waste detection unit or sorting motor) to confirm that it functions before completing the full assembly. This helps us identify and fix issues early, instead of waiting until the very end. Once everything is connected, we conduct a full system test to check if the prototype operates as expected — for example, whether it correctly detects and separates different types of waste.

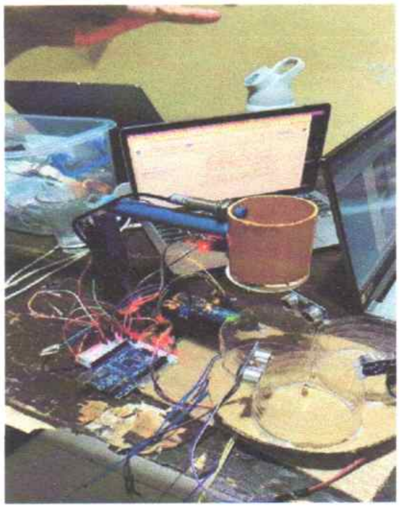
Figure 45: Subsystem

In this part is both challenging and rewarding, as it brings together all our previous work into a visible, working model. It marks an important step in making our design into a real-world solution that can contribute to better waste management and environmental sustainability.

Figure 46: Bringing our work into a visible working model

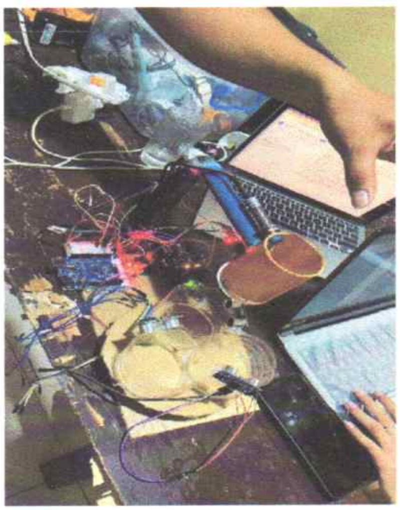
During the assembly process, we work closely as a team to ensure that every component is properly aligned, securely fastened, and connected according to the design specifications. If we encounter any fitting issues or technical problems, we stop to troubleshoot, brainstorm, and adjust as needed. Clear communication and teamwork are key at this point, as many parts must be installed in a specific order and require coordination among multiple people.

Figure 47: Properly aligning the components



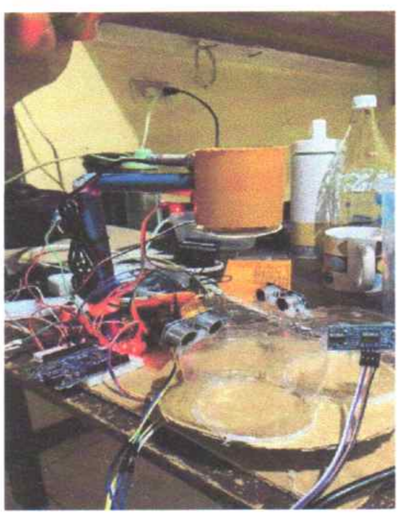
This figure shows that we have already performed trial and error, working on fixing all the sensors, jumper wires, and the breadboard connections. This process helped us ensure that every component was properly connected and functioning as expected.

Figure 48: Trial and Error



This figure shows that we also conducted trial and error testing with the two Arduinos by connecting all the jumper wires. This process helped us identify the parts of the circuit that required adjustment or troubleshooting.

Figure 49: Second Trial and Error



This figure shows that we added another Arduino and created code to control a stepper motor through the new connection. The setup demonstrates how the second Arduino integrates with the existing system to drive the motor efficiently.

Figure 50: Testing

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