International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 13, Issue 3 [March. 2024] PP: 189-200

Sensor-Based Sorting of Municipal Solid Waste using Arduino Microcontroller

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ABSTRACT: *This urban areas are facing challenges in implementing environmentally sustainable and cost-effective waste management strategies due to the growing volume and complexity of solid waste streams. One of the biggest obstacles is still the absence of automatic trash segregation systems. This article describes the development and testing of a waste segregator prototype that uses an Arduino Uno R3 to automatically classify mixed solid wastes from municipal waste streams. Multiple inductive proximity, ultrasonic, and soil moisture sensors integrated with the Arduino board are used in the segregator. Prior to building the prototype, Proteus software was used to create circuit simulations and PCB layouts for the sensor integration and control system design. The goal is to develop an automated, quick, and cost-effective system that can use real-time sensor data to intelligently separate municipal solid trash into dry, moist, and metallic fractions. A decision-making algorithm divides the garbage into predetermined groups based on sensor output data triggers after the various sensors have first analyzed the composition of the input waste stream. Extensive testing demonstrates that the sensor-enabled prototype system can effectively separate various municipal solid waste flows into the intended fractions with very accurate and dependable results. Increased use of these automated segregator systems can lead to notable gains in waste management methods' environmental sustainability and economic viability for all communities.*

Date of Submission: 16-03-2024 Date of acceptance: 31-03-2024

I. INTRODUCTION

Municipal solid waste (MSW) encompasses the diverse assortment of solid waste generated in urban areas, including household waste, waste from institutions, commercial waste, and industrial waste. This waste comprises various materials such as food scraps, paper, plastics, glass, metals, yard trimmings, and consumer electronics that are discarded as part of the regular functioning of a city. The exponential growth of population, accelerated urbanization, and industrial development have led to a substantial rise in the production of waste, making municipal solid waste (MSW) a critical global concern [1]. Managing municipal solid waste (MSW) involves many methods such as waste reduction, reuse, recycling, energy recovery, and safe disposal in landfills [2]. An effective strategy to increase the percentage of renewable energy in the overall energy output is to utilize municipal solid waste (MSW) for energy generation [3]. Regrettably, inadequate management of municipal solid waste (MSW) has resulted in health hazards, environmental pollution, and occupational accidents for waste collectors [4]–[6].

The worldwide production of MSW is projected to increase from approximately 1.3 billion tons per year in 2012 to around 2.2 billion tons per year by 2025 [1]. In view of the significant risks to human and environmental well-being resulting from the surge in garbage production, it is imperative to implement efficient waste management strategies. In addition, the improper disposal of municipal solid waste (MSW) has led to groundwater contamination and environmental degradation in many areas [7]. Governments are encountering difficulties due to insufficient management of solid waste, particularly in developing countries where population growth and urbanization have resulted in a rise in the output of municipal solid garbage [8], [9]. In addition, MSW exposes waste collectors to health problems associated with their occupation, since they frequently come into close proximity with hazardous compounds in the waste [4]. Moreover, MSW management entails many hazards that pose a threat to the well-being and safety of waste management experts [6]. To safeguard the well-being of the general public and workers, it is imperative to implement efficient waste management protocols due to the potential health hazards associated with MSW.

The effective organization and recycling of municipal solid waste (MSW) are becoming more crucial in urban areas, leading to an urgent need for its management [10]. The implementation of sensor-based technologies in solid waste sorting has shown great potential for enhancing waste management systems and achieving good outcomes [10]. The study gaps indicate a lack of understanding regarding the elements that influence community engagement in home waste sorting, especially in developing nations [11], [12]. In addition, the challenges associated with handling electronic trash, commonly known as "e-waste," in developing countries highlight the importance of having efficient recycling facilities and promoting the remanufacturing of items to extend their lifespan [13]. Furthermore, an essential issue that requires further investigation is the influence of governance on the sustainable management of municipal solid waste [14].

An emerging technique that shows promise for trash management systems is automated sensor-based sorting [10]. Various sensor technologies such as X-ray scanning, fluorescence spectroscopy, and near-infrared can be employed to distinguish different types of rubbish as they pass along a conveyor belt [15]. The complex automated sorting procedure employs a hydraulic robotic arm in [16]. The availability of cost-effective microcontrollers, such as Arduino, has enabled the development of customized sorting systems that rely on sensors [17]. Despite the utilization of PIC and Raspberry Pi microcontrollers [18]–[19] to assess sensor-based waste segregators, there is a scarcity of study on implementing Arduino-based systems.

This study presents a proposed automated waste segregation system that incorporates many sensor technologies and an Arduino Uno board. The main objectives are to develop a cost-effective and uncomplicated system that is efficient for waste management activities on a small scale.

II. METHODOLOGY

Fig. 1 depicts the comprehensive technique or sequence of procedures employed in creating the waste segregation system utilizing Arduino UNO R3. The procedure commences with a comprehensive examination of existing literature, wherein established methodologies, constraints, and areas of research deficiency in waste management and segregation are scrutinized. This step is crucial in developing the project objectives and design specifications. Subsequently, the project design is defined by establishing the specifications, which encompass the choice of hardware components (such as Arduino UNO R3, sensors, and servo motor), system prerequisites, and the comprehensive system structure. The hardware development phase entails the integration of the chosen components, constructing the circuit on a breadboard or PCB, and verifying the correct connections and functionality of the hardware elements. Concurrently, software development occurs, in which the Arduino UNO R3 is developed using the Arduino IDE to manage the sensors, analyze the input signals, and drive the servo motor for waste segregation. After the development of the hardware and software components, the integration and testing phase commences. During this phase, the hardware and software components are integrated, and the entire system undergoes thorough testing in order to detect and repair any problems or glitches that may arise in different settings.

The design criteria included an automated waste segregation system that categorizes residential garbage into three distinct groups: organic waste, plastic waste, and metal waste. The system utilized an Arduino UNO R3 microcontroller as the primary control unit, in addition to three separate sensors for precise garbage detection and categorization. A soil moisture sensor was used to identify wet garbage. This sensor quantifies the volumetric water content in the trash by detecting the resistance between its two probes, which fluctuates in accordance with the moisture level. As the moisture level increases, the resistance decreases, enabling the device to properly detect wet trash. An ultrasonic sensor was integrated to identify plastic garbage. This sensor functions by producing ultrasonic waves and calculating the duration it takes for the waves to reflect off an item. The system may use time-of-flight analysis to accurately measure the distance to the waste and categorize it as either plastic or dry waste, using a predetermined threshold distance. An inductive proximity sensor was employed for the purpose of detecting metal trash. This sensor operates based on the theory of electromagnetic induction, generating a high-frequency electromagnetic field that is disturbed by the existence of metallic objects within its detection range. When a metallic waste object is inserted, the sensor detects the alteration in the electromagnetic field and notifies the system appropriately.

Furthermore, a servo motor was incorporated to control a revolving platform that has three specific compartments for each sort of waste. The servo motor, renowned for its meticulous angular manipulation, was programmed to spin the platform and align the suitable bin in front of the user for garbage disposal, depending on the identified waste category. The system was equipped with an LCD display that offered visible feedback to the user, indicating the identified type of trash and the relevant bin for disposal. The primary objective of this intuitive interface is to streamline the waste segregation process and encourage the adoption of effective waste management practices within households.

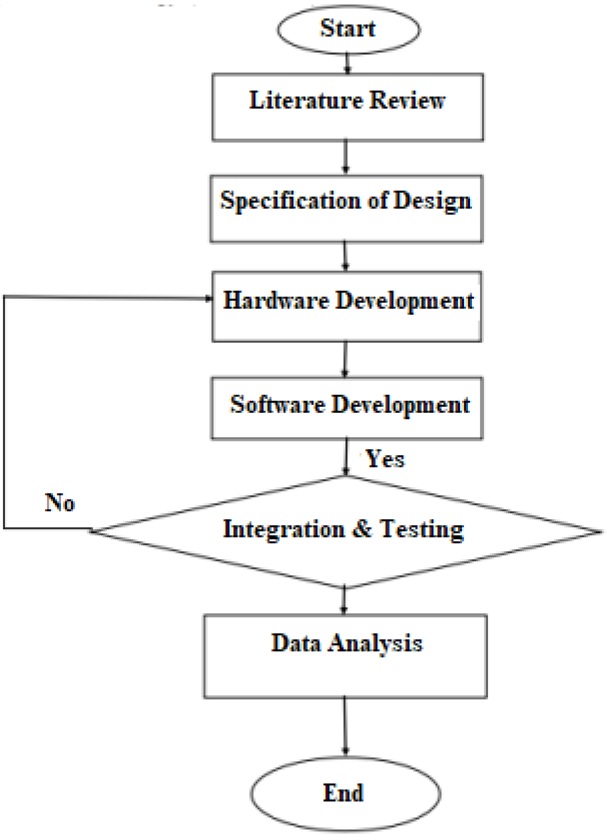


Fig. 1 Flowchart of system development process

The initial phase of hardware development entailed the assembly of components on a breadboard for the purpose of testing and resolving any issues as shown in Fig. 2. The breadboard offered a practical platform for establishing temporary connections and conducting circuit design experiments prior to finalizing a permanent printed circuit board (PCB). The Arduino UNO R3 microcontroller board was firmly affixed to the breadboard, guaranteeing accurate positioning and steadiness. The several sensors, such as the soil moisture sensor, ultrasonic sensor, and inductive proximity sensor, were strategically positioned on the breadboard, taking into account their pin configurations and connection needs. The servo motor, which is responsible for the rotation of the waste bin platform, was meticulously placed on the breadboard to ensure ample space for its movement. The LCD display module was linked to the corresponding pins on the Arduino UNO R3 in order to present feedback and instructions to the user. Special consideration was given to the arrangement of the wiring, ensuring that the connections between the components and the Arduino were systematically ordered and easily distinguishable. This aided in the identification and resolution of any potential difficulties encountered during the troubleshooting procedure. The components were connected to the Arduino using jumper wires of suitable lengths, following the schematic diagram and according to correct electrical norms.

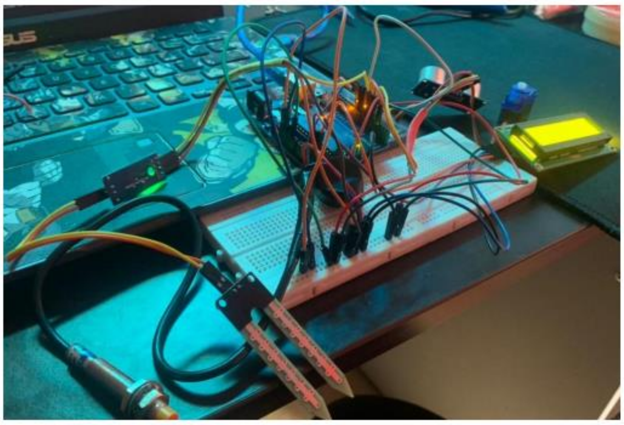
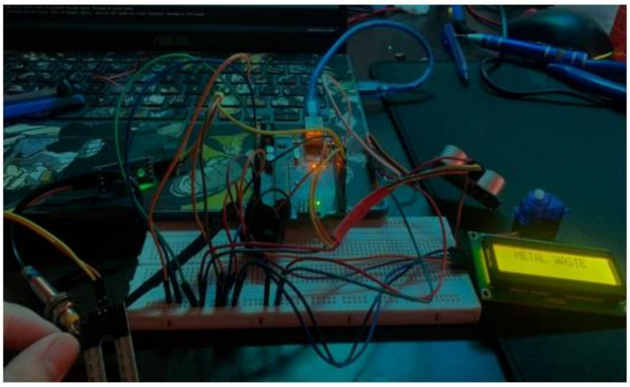
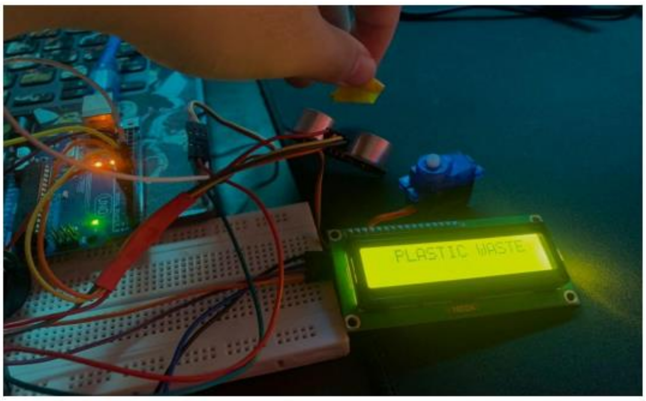


Fig. 2 Flowchart of system development process

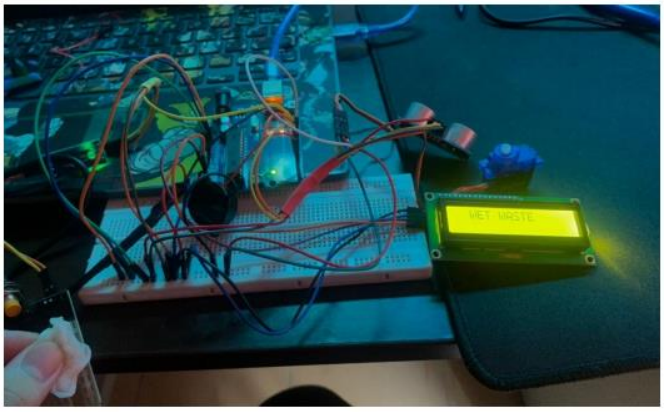
After positioning the components on the breadboard and establishing connections with the Arduino UNO R3, thorough testing and troubleshooting were conducted to verify correct operation and detect any possible problems. This procedure encompasses multiple stages, including the evaluation of sensors, the examination of servo motors, the testing of LCD displays, and the integration testing. Each sensor (soil moisture, ultrasonic, and inductive proximity) underwent separate tests to confirm its functionality and calibration as shown in Fig 3 (a), (b) and (c). The sensor data were observed and contrasted with established reference values to guarantee precise identification of waste categories. During the testing of the servo motor, various pulse width modulation (PWM) signals were sent from the Arduino to guarantee that it rotated to the specified positions (0°, 90°, and 180°) that corresponded to the locations of the garbage bins. Subsequently, the functionality of the LCD display module was evaluated by transmitting diverse textual commands from the Arduino in order to verify its accurate depiction of the identified waste category and its matching receptacle. Once the individual components were verified, the entire system underwent testing by introducing various types of trash and analyzing its overall functionality. This entailed monitoring the sensor data, confirming the rotation of the servo motor, and ensuring the accuracy of the output on the LCD display. Throughout the troubleshooting process, all problems or inconsistencies were recognized and resolved. These actions may have included fine-tuning sensor calibrations, altering the program code, verifying wiring connections, or replacing defective components as needed.



(a)



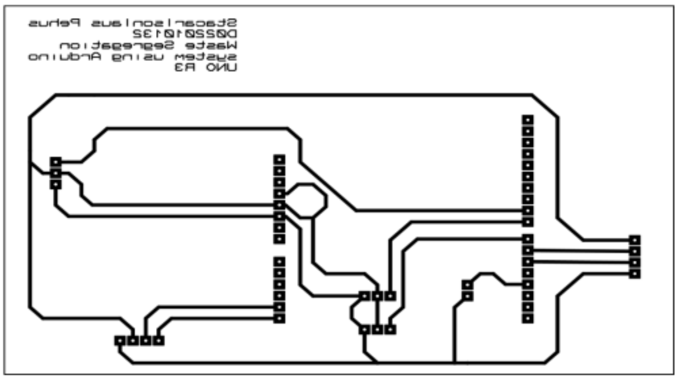
(b)



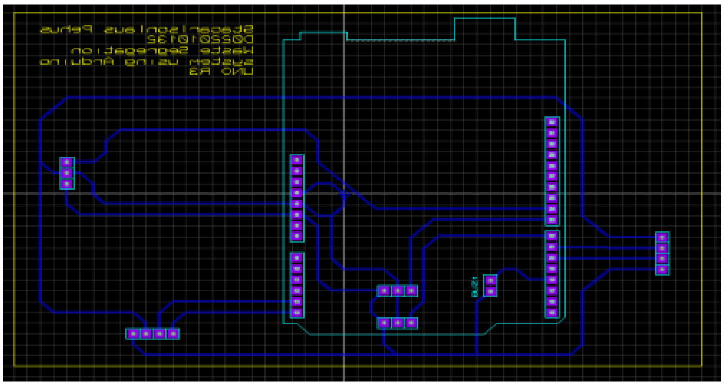
(c)

Fig. 3 (a) Metal sensor test (b) Ultrasonic sensor (c) Soil moisture test

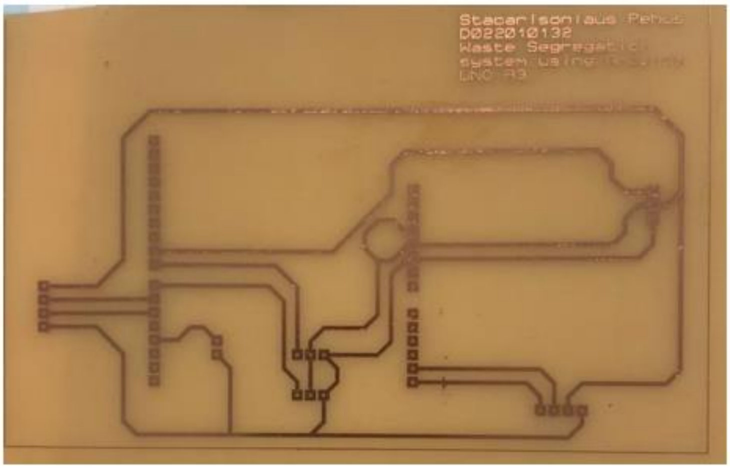
In order to achieve a small and durable end product, the circuit design was migrated from the breadboard to a printed circuit board (PCB). The PCB layout was created utilizing Proteus software, enabling accurate positioning of components and routing of circuit traces as shown in Fig 4 (a), (b) and (c). The schematic design was initially generated using the program to ensure precise depiction of the components and their interconnections. The PCB layout was carefully planned, taking into account aspects such as component spacing, trace routing, and potential electromagnetic interference (EMI) concerns, as indicated by the schematic. After the PCB layout was completed, it was printed onto a transparent film or a specialized PCB transfer paper using a high-resolution printer. This printed layout functioned as a template for transposing the circuit design onto a copper-clad board. To ensure effective adherence of the printed layout, the surface of the copper-clad board was cleaned and deoxidized. The printed pattern was transferred onto the copper-clad board using a UV exposure equipment or a similar method, resulting in a negative image of the circuit traces. Following the exposure phase, the board underwent an etching procedure in which a chemical etchant solution was employed to eliminate the undesired copper regions, thereby retaining the desirable circuit traces. This procedure necessitated meticulous supervision and stirring to guarantee thorough etching without causing harm to the intended circuitry. After the etching process was finished, the board underwent a meticulous cleaning and drying procedure to eliminate any remaining etchant or debris. Subsequently, the component pads and through-holes were perforated either by drilling or punching, facilitating the further positioning and soldering of the components. The Arduino UNO R3, sensors, servo motor, and LCD display were meticulously soldered onto the PCB, ensuring that they were placed correctly according to the layout and with the correct polarity and orientation. Following the soldering process, a thorough examination was conducted to detect any possible cold joints or shorts, thereby guaranteeing a dependable and resilient circuit. Next, the manufactured printed circuit board (PCB) was combined with the essential housing, fasteners, and any supplementary elements needed to complete the construction of the waste segregation system.



(a)



(b)



(c)

Fig. 4 (a) PCB layout for printing (b) PCB layout in Proteus (c) Final PCB layout

The software development procedure for the waste segregation system utilizing Arduino UNO R3 commences by establishing the Arduino Integrated Development Environment (IDE) on the computer and verifying the installation of the necessary libraries and drivers for the Arduino board. Subsequently, the essential constants and variables are established and initialized, encompassing sensor thresholds, servo motor positions, and pin allocations for the sensors, servo motor, and LCD display. The setup function initializes the serial interface, if necessary for debugging purposes, and sets the pin modes for the sensors and servo motor. In addition, the method initializes the LCD display. The main functionality of the program is included within the loop function. In this function, the values from the moisture sensor, ultrasonic sensor, and inductive proximity sensor are obtained using the relevant Arduino functions or libraries. The program utilizes conditional statements, such as if-else statements, to create waste detection logic based on the sensor values. If the moisture sensor reading over a predetermined threshold, the garbage is classified as "Wet Waste." If the value of the ultrasonic sensor falls below a specific distance threshold, the waste is categorized as "Plastic Waste." When the inductive proximity sensor detects metal, it categorizes the garbage as "Metal Waste." Once the waste kind is identified, the program transmits the suitable PWM signal to the servo motor, which in turn rotates to the assigned position that corresponds to the waste bin specifically meant for that waste type. Subsequently, the waste kind that has been detected and its related bin are exhibited on the LCD display by utilizing the suitable functionalities from the LCD library. During the development process, the program undergoes constant testing and debugging by introducing various waste types and evaluating the sensor readings, servo motor rotation, and LCD display output. The code is optimized and refined to improve efficiency, and any necessary extra features or error handling procedures are added. After the software is finished and extensively tested, it is sent to the Arduino UNO R3 board using the upload feature of the Arduino IDE. The software development process strictly adheres to best coding practices, which include utilizing descriptive variable names, incorporating comments to enhance code readability, and following the Arduino programming conventions and rules. Fig. 5 shows the pseudo code of system.

```
Initialize variables and constants
Set sensor thresholds
Set servo motor positions for waste bins

Loop:
    Read moisture sensor value
    Read ultrasonic sensor value
    Read inductive proximity sensor value

    If moisture sensor value > moisture threshold:
        Identify waste as "Wet Waste"
        Rotate servo motor to wet waste bin position
        Display "Wet Waste" on LCD
    Else If ultrasonic sensor value < distance threshold:
        Identify waste as "Plastic Waste"
        Rotate servo motor to plastic waste bin position
        Display "Plastic Waste" on LCD
    Else If inductive proximity sensor detects metal:
        Identify waste as "Metal Waste"
        Rotate servo motor to metal waste bin position
        Display "Metal Waste" on LCD
    Else:
        Display "Invalid Waste" on LCD

End Loop
```

Fig. 5 Pseudo code of system

During operation, the waste segregation system operates in the following manner: Upon the introduction of garbage into the system, the sensors promptly identify the sort of waste by analyzing their respective principles, which include moisture level, distance, and metal presence. The Arduino microcontroller analyzes the sensor inputs and identifies the correct waste category. Subsequently, it transmits a signal to the servo motor, prompting it to spin the platform and align the suitable bin in front of the user for waste disposal. The LCD display of the system gives visual feedback by identifying the identified waste type and the corresponding bin to be utilized. This automated procedure streamlines trash segregation for residential users, advocating for appropriate waste management and facilitating effective recycling or disposal methods. Fig. 6 shows the operation of system.

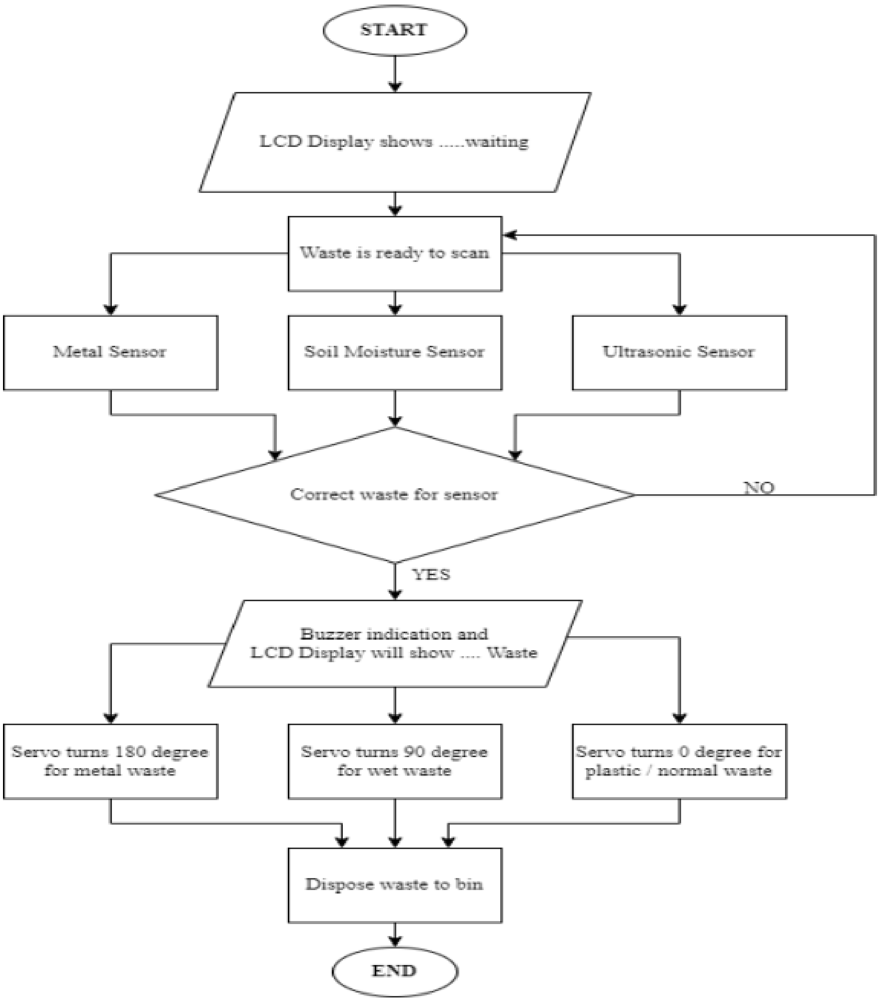


Fig. 6 Flowchart of system operation

III. RESULTS AND DISCUSSION

Fig. 7 shows the circuit connection of system. The circuit connection for the waste segregation system was devised using Proteus software, guaranteeing seamless integration of all components. The Arduino UNO R3 microcontroller functioned as the primary control unit, facilitating communication between the sensors and actuators. The soil moisture sensor was attached to the 7th digital pin of the Arduino, which is used to detect the presence of moisture in the soil. The ultrasonic sensor was utilized to distinguish between plastic and dry garbage, with its trigger attached to the 6th pin and its echo connected to the 5th pin. The inductive proximity sensor, despite its absence in the Proteus library, was utilized in the hardware prototype to identify and locate metallic debris. The servo motor, linked to the 8th pin, rotated the bin platform according to the detected waste category. The user was provided with visual feedback using an LCD display that was connected to the A5 and A4 pins using an I2C module. This feedback indicated the type of trash that was detected and the appropriate bin. In addition, an audible buzzer was linked to the 3rd pin to offer notifications when waste was detected.

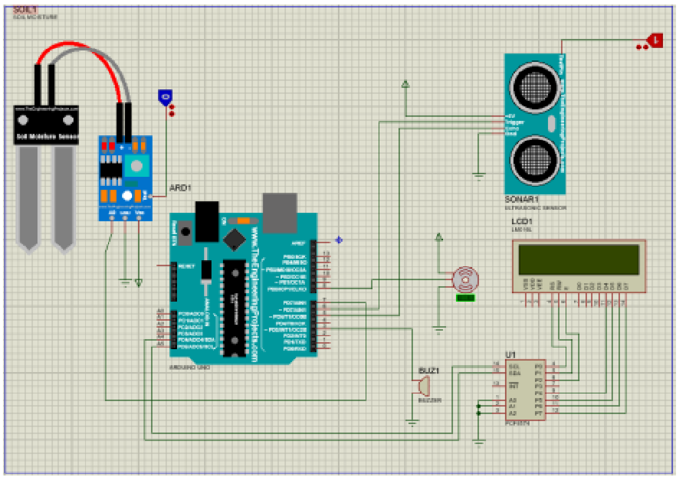
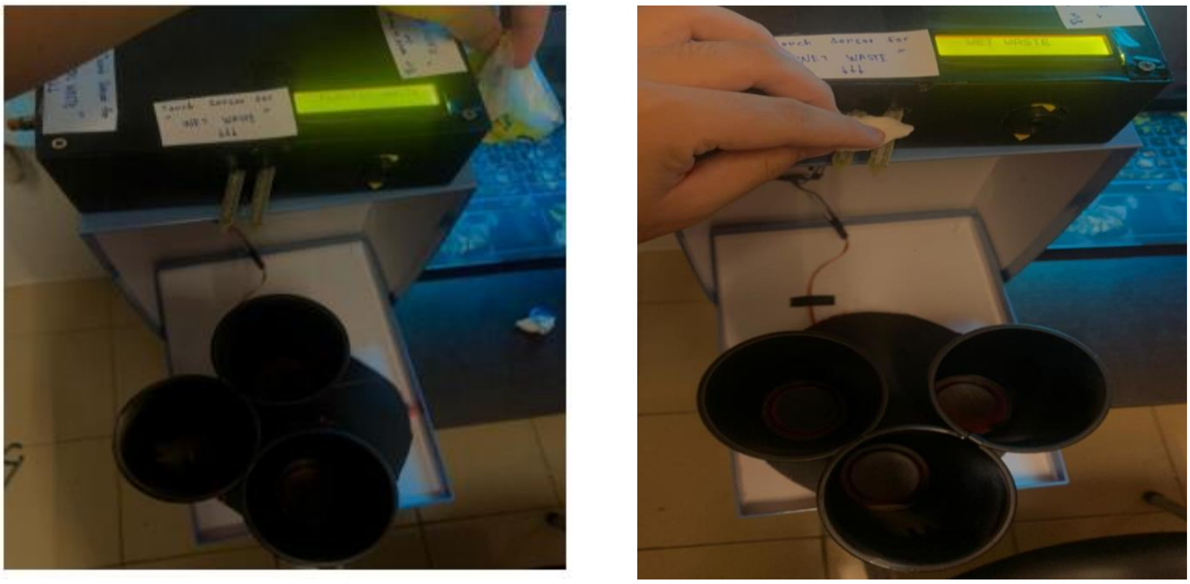


Fig. 7 Circuit connection of system

The trash segregator system effectively showcased its ability to identify and separate garbage into three distinct categories: organic waste, plastic waste, and metal waste. Upon the introduction of a waste item into the system, the sensors promptly and precisely detected its properties. When the soil moisture sensor detects a high moisture level, the system categorizes the garbage as "Wet Waste" and moves the servo motor to place the wet waste bin in front of the user as shown in Fig. 8(a). Moreover, in the event that the ultrasonic sensor identified an object within a predetermined distance limit, the system categorized the garbage as "Plastic Waste" and adjusted the rotation of the bin platform accordingly as shown in Fig. 8(b). Upon detecting the presence of metal, the inductive proximity sensor categorizes the waste as "Metal Waste" and locates the appropriate metal waste bin as shown in Fig. 8(c). The LCD display presented explicit directions to the user, specifying the identified waste category and the matching receptacle for proper disposal.



(a) **(b)**

(c)

Fig. 8 (a) Turns 0° for plastic waste (b) Turns 90° for wet waste (c) Turns 180° for metal waste

A fully operational prototype of the waste segregation system utilizing Arduino UNO R3 was effectively created and examined as shown in Fig. 9. The prototype comprised the Arduino UNO R3 board, a soil moisture sensor, an ultrasonic sensor, an inductive proximity sensor, a servo motor, an LCD display, and three designated waste bins affixed to a revolving platform. The sensors were strategically positioned to identify the specific attributes of the garbage, and the servo motor adjusted the bin platform accordingly, aligning it with the detected waste category. The LCD display offered intuitive feedback, assisting the user in navigating the trash disposal procedure.

Fig. 9 Final Prototype of system

For the discussion, the garbage segregation system designed using Arduino UNO R3 has the capacity to make a substantial contribution to sustainability and environmental conservation initiatives. The technology enhances waste management practices and streamlines recycling and disposal operations by automating waste sorting at the household level. Historically, home waste has commonly been combined and disposed of without discrimination, resulting in environmental contamination and difficulties in recycling and reclaiming resources. The trash segregation system tackles this problem by dividing garbage into specific categories, facilitating improved waste management and utilization of resources. By separating garbage into different categories, it is possible to recycle it more efficiently, which in turn reduces the strain on landfills and minimizes the negative effects of incorrect waste disposal on the environment. Moreover, the method enhances the knowledge of households regarding the significance of waste segregation and promotes responsible waste management practices. Through the implementation of a user-friendly and automated solution, the system has the ability to effectively impact behavior and foster a culture of environmental awareness. Moreover, the waste segregation system has the potential to be incorporated into broader waste management frameworks, so enhancing the overall sustainability endeavors of municipalities or waste management organizations. By optimizing the waste segregation process at its origin, the system can improve the effectiveness of subsequent processes, such as material retrieval, composting, and energy generation from waste. In summary, the trash segregation system designed using Arduino UNO R3 is a practical and unique solution that adheres to the ideals of sustainable development and environmental preservation. The system contributes to a more sustainable future and a healthier environment by advocating for effective waste management, enabling the recovery of resources, and promoting responsible garbage disposal through increased awareness.

IV. CONCLUSION

The utilization of Arduino UNO R3 in creating a trash segregation system has effectively showcased the capabilities of automation and technology in tackling the difficulties associated with managing MSW. The primary results of the experiment emphasize the system's efficiency in precisely identifying and separating home garbage into three specific categories: organic waste, plastic waste, and metal waste. However, future endeavors may entail broadening the system's functionalities to accept more forms of waste or integrating more sophisticated sensor technologies to enhance waste identification. Integrating with Internet of Things (IoT) technology has the potential to facilitate remote monitoring and data collecting, offering significant insights for waste management enterprises and municipal authorities. Moreover, the system has the potential to be expanded and implemented in bigger residential communities, business establishments, or even at the municipal level, thereby amplifying its influence on waste management methods. Engaging in cooperation with local authorities and trash management agencies could streamline the incorporation of the system into current waste collection and processing frameworks, hence enhancing the overall effectiveness and environmental friendliness of MSW management plans.

REFERENCES

[1]. Rawat, S., Rai, M., & Bhadoria, S. (2020). Assessment of waste to energy generation potential of municipal solid waste: A case study of South Delhi. In Lecture Notes in Civil Engineering (pp. 127–134).

[2]. Chabuk, A., et al. (2016). Solid waste shredder design parameters based on experimental and theoretical studies". Applied Mathematical Modelling, 40(2), 954–967.

[3]. Scarlat, N., Fahl, F., & Dallemand, J. (2018). Status and opportunities for energy recovery from municipal solid waste in Europe. Waste and Biomass Valorization, 10, 2425–2444.

[4]. Bogale, D., Kumie, D., & Tefera, W. (2014). Assessment of occupational injuries among Addis Ababa city municipal solid waste collectors: A cross-sectional study. BMC Public Health, 14(169).

[5]. Melaku, Y., & Tiruneh, A. (2020). Occupational health and safety practices and safety behavior among municipal solid waste workers in Bahir Dar city, northwest Ethiopia. BMC Public Health, 20(1023).

[6]. El-Wahab, R., & Eassa, A. (2019). Risk assessment for handling municipal solid waste in Egypt. Egypt Journal of Occupational Medicine, 43, 101–118.

[7]. Zagozewski, R., Jurado-Guerrero, G., Neyra, D., & Indacochea, M. (2011). Environmental impact of municipal solid waste disposal in Chiclayo, Peru. Journal of Environmental Protection, 2(9), 1200–1210.

[8]. Gumisiriza, R., & Kugonza, D. (2020). Solid waste management practices and factors influencing adoption of source separation of waste in urban areas of Uganda: A case of Kampala Capital City Authority. Habitat International, 104, 102235.

[9]. Bhuiyan, S. (2010). A crisis in governance: Urban solid waste management in Bangladesh. Habitat International, 34(1), 125–133.

[10]. Zhao, Y., & Li, Q. (2022). Smart waste sorting technology: A review. Sustainability, 14(8), 4826.

[11]. Rousta, K., Bolton, C., Lundin, M., & Danterand, B. (2020). Quantitative meta-analysis of mobile waste management systems for source separation and collection. Waste Management Research, 38(5), 474–483.

[12]. Santoso, L., & Farizal, I. (2019). Household behavior and perspective on solid waste management in Indonesia: A study from Indonesia 100 Cities. IOP Conference Series: Earth and Environmental Science, 399(1), 012076.

[13]. Osibanjo, O., & Nnorom, I. (2007). The challenge of electronic waste (e-waste) management in developing countries. Waste Management Research, 25(6), 489–501.

[14]. Gachoki, C., et al. (2022). Assessing the influence of governance on sustainable municipal solid waste management: A case study of developing countries. Environmental Science and Pollution Research, 29, 8394–8411.

[15]. Dubanowitz, J. (2000). Design of a materials recovery facility (MRF) for processing the recyclable materials of New York City's municipal solid waste (Master's thesis). Columbia University, New York, NY, USA.

[16]. DellJesse, M., Yiannosiep, D., & Kazihran, I. (2000). Robotic material recovery facility for municipal waste sorting (U.S. Patent No. 6,137,074).

[17]. Sharma, A., Shukla, S., & Chowdhary, R. (2019). Smart waste sorting system for municipal solid waste. In Proceedings of the 2nd International Conference on Computer Communications and Devices (pp. 1–4).

[18]. Zahra, T., Dharavath, A., Challuri, S., & Meti, S. (2020). Smart dustbin for waste segregation and status alert system. In Proceedings of the 2nd International Conference on Intelligent Communication and Computational Technologies (pp. 759–763).

[19]. Zhong, R., Zhang, Y., Huang, T., Liu, Q., Xu, J., & Li, Y. (2018). Raspberry Pi-based smart trash bin using Internet of Things. In Proceedings of the IEEE 4th International Conference on Computer Communications (pp. 1712–1714).