# Leveraging Intelligent Waste Segregation System for Renewable Energy and Environmental Sustainability

Olaitan O. Afolabi
Department of Information and Communication Engineering, Elizade University, Ilara Mokin, Nigeria.
olaitan.afolabi@elizadeuniversity.edu.ng

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ORIGINAL RESEARCH

**Abstract**— The continuous increase in human population across the world's continents has given rise to the volume of waste generated. Improper waste management poses environmental and health risk, as such it is paramount to take meticulous measures to manage waste. Waste segregation facilitates the collection of recyclable materials and the safe disposal of non-recyclable ones. The manual method of waste segregation is unhygienic, costly, and time-consuming. This work proposes an Intelligent Waste Segregation System to cater for these setbacks. The proposed system integrates the working principle of inductive proximity, capacitive, and moisture sensors to identify and classify waste materials into metal, paper, plastic, and wet materials respectively while the Arduino microcontroller serves as the coordinating unit for all detection and classification activities. This way, the recyclable materials can be collected for further processing and the non-recyclable wastes can be disposed of in an environmentally friendly manner. The results of multiple tests of the developed system with the identified materials show 84.4% success rate, which makes it reliable for implementation in real-life systems. Deploying this solution in homes and industrial environments can foster resource optimization and hygienic waste management for environmental sustainability.

**Keywords**— Intelligent System, Recycling, Renewable Energy, Sensor, Waste Segregation.

## 1 Introduction

Efficient management of waste is a fundamental requirement of humanity. This is necessary in order to promote a healthy environment as well as optimize resources. Environmental pollution constitutes many health issues like the spread of communicable and non-communicable diseases. A report shows that 90% of infant deaths are caused by air and water pollution in low-income countries (Siddiqua *et al.*, 2022). The production of plastic products from raw materials like natural gas and crude oil presently accounts for 5% of global oil consumption with an average projection of a 20% increase by 2050, which contributes to depletion of natural resources (Vollumer *et al.*, 2020). This reliance also results in environmental concerns like greenhouse effects. As reported by Afolabi (2018), 85% of electronic waste ends up in landfills. Improper disposal of waste into oceans and farmlands has caused severe damage to agriculture, marine life and human health (Balogun-Adeleye *et al.*, 2022; Leslie *et al.*, 2022).

Waste segregation helps in the collation of materials into their forms for further processing. Through this, non-reusable wastes can be hygienically disposed of or used as soil manure for agricultural purposes, while reusable ones can be recycled (Amjith & Bavanish, 2022). Wastes like paper, plastic and metal can be recycled to fabricate new materials. While biomass and plastic wastes can equally generate heat and electrical energy through processes like combustion, gasification, anaerobic digestion or incineration (Gutiérrez *et al.*, 2020; Xayachak *et al.*, 2023; Ahmad *et al.*, 2024). Metals manufactured from waste materials require far lesser amount of energy compared with virgin ores (Farzadkia *et al.*, 2021). To identify the useful waste materials that can be profitably recycled, there is a need for an effective segregation technique.

This work design and implements an intelligent waste segregation system with a robust capability to identify wet and dry wastes of which the dry materials can also be classified as paper, plastic and metal. The technology used integrates the working principles of Arduo Uno microcontroller and a variety of sensor technologies such as capacitive, inductive proximity and moisture sensors to identify and sort materials. The subsequent sections of this paper identifies and discuss some existing approach of waste segregation, the methodology introduced in this work, the results and finally concludes based on the outcome of the results.

## 2 Review Of Related Works

The manual method of waste sorting is known to be the most simple and direct method of waste segregation. In some cases, provisions are made for separate bins for different waste materials at the point of collection. The major issues with this methods include; people's unwillingness to participate, inability of participants to correctly classify materials and low sorting rate (Chahine & Ghaza, 2017). Many automated waste sorting systems has been introduced using artificial intelligence (AI), sensors and microcontroller technology. In Torres-García *et al.* (2015) and Desai *et al.* (2018) integrated image processing, machine learning and computer vision

*Corresponding Author

**Section B-** ELECTRICAL/COMPUTER ENGINEERING & RELATED SCIENCES
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techniques into algorithms like the k-Nearest Neighbor (k-NN) to train their systems for intelligent waste sorting. Al Rakib *et al.* (2021) interfaced dampness and ultrasonic sensors with arduino microcontroller to separate waste materials and notify the authority for collection given certain threshold through the GSM module. Sravya *et al.* (2023) separates waste into wet, dry and metal through their solution. Varsha & Karnika (2024) introduced a home based multipurpose waste segregator robotics using the working principles of sensors to identify, measure, perceive, relocate and waste while alerting the personnel overseeing the system at the same time.

However, some of these works are limited to inorganic waste sorting while others restrict their solutions to dry or wet waste segregation or either of the two. This work fills up the afore-mentioned gaps by implementing a sensor based intelligent waste system with a robust capability to identify wet and dry wastes of which the dry materials can also be classified as paper, plastic and metal. The system is cost efficient with easily accessible component which makes it suitable for implementation in homes and industries.

## 3 Methodology

The methodology used in developing proposed system constitutes the description of the hardware and software modules, system implementation and the experimental procedure.

### 3.1 Hardware And Software Modules

The hardware module of the following consists of the following:

- Arduino Uno R3: This ATmega328 based microcontroller consists of 14 digital input/output pins (6 of these pins can serve as Pulse Width Modulation outputs), 6 analog inputs, a power jack, a universal serial bus (USB) connection, a 16 MHz resonator, and a reset button (Suvarnamma & Pradeepkiran, 2021). The choice of the microcontroller is due to its ease of use for electronic projects.
- Sensor unit: The sensor unit incorporates two moisture sensors, an inductive proximity sensor and two capacitive sensors.
    - The moisture sensors are used for detecting wet and dry waste materials respectively. The sensor classifies based on the changes in the electrical resistance between the two electrodes of a sensor. The resistance is low when a wet waste is detected while it is high when a dry waste is detected. The moisture sensors are connected to the analog input pins A0 and A1 of the Arduino which receives the moisture content measured in a given material through the interface as input signals.
    - The inductive proximity sensor is interfaced with the Arduino board through pin 3. To sense a metallic object, an electromagnetic field is generated on the coil and oscillator within the sensor's detection zone. This field causes a reduction of the oscillation amplitude which is converted into an electrical signal sent as input to the Arduino.
    - The capacitive proximity sensors are used to detect paper and plastic materials. It classifies materials as paper or plastic by checking the values of the dielectric constant of the material. This value is set to high for paper and low for plastic given a specific threshold. These sensors which are connected to pins 2 and 4 of the Arduino receive detected signals and sends them as input signals to the Arduino.
- Direct Current (DC) motor: This motor controls the motion of the bin in a rotatory manner. The electrical energy supplied is converted to mechanical energy that generates the motion. It is relayed with the Arduino board on pin 10. The direction of the motor's rotation is determined by the output signal received from the microcontroller.
- Servo motor: This is a servo-mechanism driven motor, used for controlling angular positioning, speed and flipping of the waste placed on the sensor plate into the bins. The motor is connected to pin 9 on the Arduino board.
- Power supply unit: For this project, the switch mode power supply was selected as the power source for the hardware components. It powers the Arduino board and supplies regulated voltages of +12V and +5V (DC) to the sensors and motors respectively.
- Bin: A bin with four partitions was provided to receive the classified wastes.
- Micro-switch: Micro-switches are used to detect the passage of a moving part and to stop the motion of the bin whenever it receives a signal. Four of these switches are integrated with Arduino board to facilitate the stoppage of the bin at the intended positions via pins 5, 6, 7 and 8.
- Relay: A relay was used to initiate the movement of the DC motor using open and close contact. The device operates with an electromagnetic mechanism to perform open and close functions.
- Buck converter: Two buck converters are provided to regulate the input voltages to the DC motor and Servo motor. It steps down the 12V input voltage to supply the DC motor and Servo motor with 2.5V and 5V respectively.
- The software module is made up of the Arduino Independent Development Environment (IDE) which is used to develop the codes that control the Arduino hardware and other circuit connections. The IDE compiles and translates the codes written in C++ to assembly language, and uploads the program to the Atmega328 microcontroller.

### 3.2 System Implementation

The sequence of components integration of the Intelligent Waste Segregation System is shown in Figure 1. Figure 2 shows the prototype integration process while Figure 3 presents the prototype of the proposed system in its complete form. The bin is divided into four compartments labelled as partition 1, 2, 3 and 4. Each of these partitions is designed to collect paper, wet waste, metal and plastic materials respectively. The program that operates the system was developed using C++ programming

 

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language and uploaded on the Arduino Uno board through the Arduino IDE.

### 3.3 EXPERIMENTAL PROCEDURE

Experiments were carried out to test the performance of the developed Waste Segregation System using different types of materials. The system was switched on through a power source and detection activities were initialized by the sensors when a waste material was placed on the system tray (also known as the waste detection zone). The microcontroller received the sensed signal from the sensors and issued an output signal; which also moved the DC motor to the direction of the appropriate bin partition.

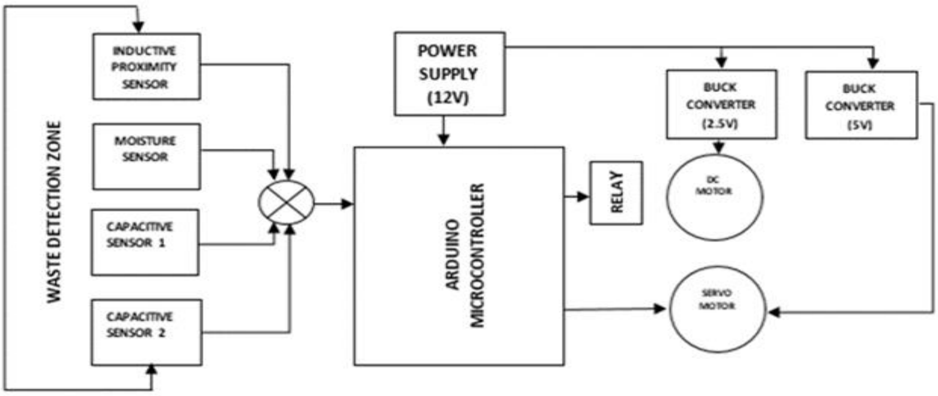


Fig. 1. Block Diagram of the Intelligent Waste Segregation System Mechanism

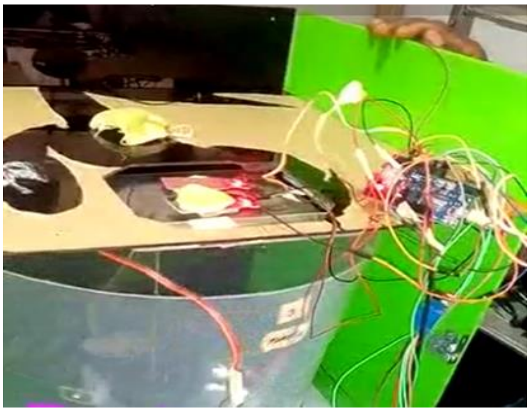

Fig. 2. Prototype Integration of the Intelligent Waste Segregation System

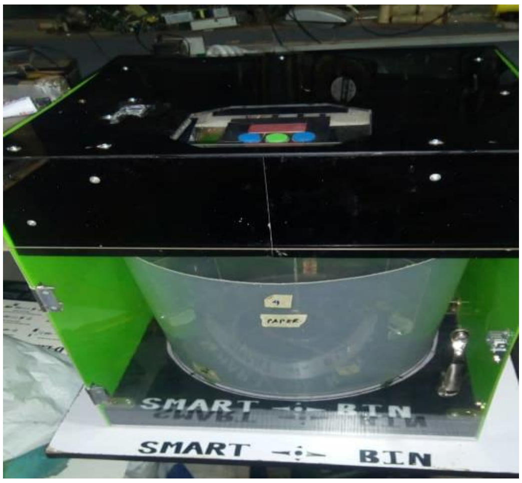


Fig. 3. Prototype of the Integration of the Intelligent Waste Segregation System

If the moisture sensors detect the waste, the motor rotates the bin to position the waste above Partition 1. If the inductive sensor detects a metallic object, the motor rotates the bin to position the waste above Partition 2. If the first capacitive sensor detects a paper, the motor rotates the bin to position the waste above Partition 3. If the second capacitive sensor detects a plastic material, the motor rotates the bin to position the waste above Partition 4. The waste placed on any of the partitions drops inside when the Servo motor flips open the cover by 90 degrees. Figure 4 shows the workflow of the intelligent waste segregation system.

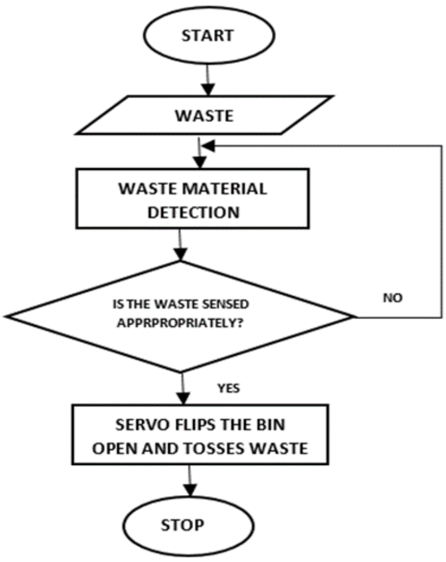


Fig. 4. Intelligent Waste Segregation Work Flow



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## 4. Results And Discussion

Table 1 shows the results of the experiment carried on the Intelligent Waste Segregation System using different types of materials. It can be seen that the system failed in detection of certain materials during the first and second experiments, however, it shows a good performance after all, with twenty-seven (27) correct classifications from a total of thirty-two (32) runs. This result amounts to 84.4 % success rate; which makes it suitable enough for real-life implementation.

**Table 1. Experimental Results of the Intelligent Waste Segregation System**

| WASTE | MATERIAL | EXPERIMENTAL RESULTS | | | |
|---|---|---|---|---|---|
| | | Experiment 1 | Experiment 2 | Experiment 3 | Experiment 4 |
| Wet | Banana | ✓ | ✓ | ✓ | ✓ |
| | Orange | X | ✓ | ✓ | ✓ |
| Plastic | Plastic card | X | ✓ | ✓ | ✓ |
| | Plastic bottle | ✓ | ✓ | ✓ | ✓ |
| Paper | A single paper | ✓ | ✓ | ✓ | ✓ |
| | Multiple papers | X | X | ✓ | ✓ |
| Metal | Ferrous | ✓ | ✓ | ✓ | ✓ |
| | Non-ferrous | X | ✓ | ✓ | ✓ |

Key

| | |
|---|---|
| Correct classification | ✓ |
| Incorrect classification | X |

## 5 Conclusion

By convention, waste segregation is usually managed at the municipal level due to intensive resource requirements, this work has thus created an opportunity for individuals to implement the same with minimum budgets as well as provide resources for stakeholders who are involved in recycling activities. Our solution also possess the potential to encourage the practice of renewable energy using the segregated waste. This can foster job creation, technological advancement and environmental sustainability. We look forward to deploying deep learning algorithms in place of sensors, as well as designing the model for concurrent classification of multiple types of waste materials in our future work. This will enhance the system with higher classification accuracy performance and facilitate better time management.

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## References

Al Rakib, M. A.; Rana, M. S.; Rahman, M. M.; and Abbas, F. I. (2021). Dry and wet waste segregation and management system. European Journal of Engineering and Technology Research, 6(5), 129-133, https://doi.org/10.24018/ejeng.2021.6.5.2531

Afolabi, O. O. (2018). WWW: What e-wastes worth. Academic Journal of Science (AJS), 08(02), 267–274.

Ahmad, N., Sanni, A., Ahmad, A., and Aliyu, S. (2024). Fabrication of mini bio-gas digester using locally available material for cooking purposes. FUOYE Journal of Engineering and Technology, 9 (2), https://dx.doi.org/10.4314/fuoyejet.v9i2.1

Amjith, L. R., and Bavanish, B. (2022). A review on biomass and wind as renewable energy for sustainable environment. Chemosphere, 293, 133579, https://doi.org/10.1016/j.chemosphere.2022.133579

Balogun-Adeleye, R. M., Adu, J. T., and Adisa, R. O. (2022) Assessment and impacts of metal recycling on groundwater quality in Ogijo, Ogun State, Nigeria. FUOYE Journal of Engineering and Technology, 7(2), https://doi.org/10.46792/fuoyejet.v7i2.781

Chahine, K., and Ghazal, B. (2017). Automatic sorting of solid wastes using sensor fusion. International Journal of Engineering and Technology, 9(6), 4408-4414, DOI: 10.21817/ijet/2017/v9i6/170906127

Desai, Y., Dalvi, A., Jadhav, P., and Baphna, A. (2018). Waste segregation using machine learning. International Journal for Research in Applied Science and Engineering Technology, 6(3), 537-541, http://doi.org/10.22214/ijraset.2018.3086

Farzadkia, M., Mahvi, A. H.; Norouzian Baghani, A.; Sorooshian, A.; Delikhoon, M.; Sheikhi, R.; and Ashournejad, Q. (2021). Municipal solid waste recycling: Impacts on energy savings and air pollution. Journal of the Air & Waste Management Association, 71(6), 737-753, https://doi.org/10.1080/10962247.2021.1883770

Gutiérrez, A. S.; Eras, J. J. C.; Hens, L.; and Vandecasteele, C. (2020). The energy potential of agriculture, agroindustrial, livestock, and slaughterhouse biomass wastes through direct combustion and anaerobic digestion. The case of Colombia. Journal of cleaner production, 269, 122317, https://doi.org/10.1016/j.jclepro.2020.122317

Kondaveeti, H. K.; Kumaravelu, N. K.; Vanambathina, S. D.; Mathe, S. E. and Vappangi, S. (2021). A systematic literature review on prototyping with Arduino: Applications, challenges, advantages, and limitations. Computer Science Review, 40, 100364, https://doi.org/10.1016/j.cosrev.2021.100364

Leslie, H. A.; Van Velzen, M. J.; Brandsma, S. H.; Vethaak, A. D.; Garcia-Vallejo, J. J. and Lamoree, M. H. (2022). Discovery and quantification of plastic particle pollution in human blood. Environment international, 163, 107199, https://doi.org/10.1016/j.envint.2022.107199

 

Siddiqua, A., Hahladakis, J. N. and Al-Attiya, W. A. K. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. Environmental Science and Pollution Research, 29(39), 58514-58536, https://doi.org/10.1007/s11356-022-21578-z

Suvarnamma, A. and Pradeepkiran, J. A. (2021). SmartBin system with waste tracking and sorting mechanism using IoT. Cleaner Engineering and Technology, 5, 100348, https://doi.org/10.1016/j.clet.2021.100348

Torres-García, A., Rodea-Aragón, O., Longoria-Gandara, O., Sánchez-García, F., & González-Jiménez, L. E. (2015). Intelligent waste separator. Computación y Sistemas, 19(3), 487-500, doi: 10.13053/CyS-19-3-2254

Vollmer, I.; Jenks, M. J.; Roelands, M. C.; White, R. J.; Van Harmelen, T.; De Wild, P.; and Weckhuysen, B. M. (2020). Beyond mechanical recycling: giving new life to plastic waste. Angewandte Chemie International Edition, 59(36), 15402-15423. https://doi.org/10.1002/anie.201915651

Varsha, A., and Karnika, S. (2024). Smart Waste Segregation System. In 2024 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE) (pp. 1-4). IEEE, https://doi.org/10.1109/IITCEE59897.2024.10467618

Xayachak, T.; Haque, N.; Lau, D.; Parthasarathy, R. and Pramanik, B. K. (2023). Assessing the environmental footprint of plastic pyrolysis and gasification: a life cycle inventory study. Process Safety and Environmental Protection, 173, 592-603, https://doi.org/10.1016/j.psep.2023.03.061