Arduino-Based Automated Waste Segregation System for Efficient Recycling

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Abstract

Now-a-days, the environment faces many challenges relating to effective waste management, particularly with the rapid population growth and increasing levels of solid waste produced in urban areas. The waste misclassification of generation contributes to the ineffectively recycling and eventually contributes to pollution. Traditional systems for sorting waste are largely dependent on manual methods that are labour-intensive and may not produce the desired result. This paper presents solutions to the previously mentioned issues by presenting a prototype for an automated waste sorting system using an Arduino platform. The system will enable the separation of wet and dry waste through sensor technology. The moisture content of the waste will be determined from moisture sensors identify the type of waste. Data from these sensors is sent and processed by an Arduino Uno microcontroller. When a waste material is determined to have a certain classification, the waste will automatically be sorted into the appropriate bin via one of the servo motor mechanisms., Ultrasonic fill level sensors exist to measure bin contents and buzzer alerts activate when bins are full to prevent waste overflow. The design demonstrated that the waste classification satisfied the classification and completed testing by reducing the amount of time spent performing manual tasks. The existing system is also cost effective and easily expanded for the use of any number

of applications including residential spaces, educational facilities and small-scale waste collection businesses.

1. Introduction

Today, waste is generated rapidly with the growth of urbanization and economic development caused by industrial sectors. Therefore, waste management is increasingly becoming a major issue both from a social and environmental perspective. Improper waste disposal can result in serious impacts on the environment such as pollution of the soil, drinking water supplies and the release of hazardous gases into the atmosphere. One of the most effective and efficient ways of improving the management of waste is through the proper segregation of waste at the source. Accurate segregation of waste will enhance the efficiency of recycling processes and significantly reduce the amount of waste generated required to be disposed in a landfill. Waste is divided into two categories related to biodegradability: wet waste and dry waste. Wet waste predominantly consists of organic matter such as food leftovers, vegetable peels and other materials that may decompose naturally. Alternatively, dry waste consists of plastic, paper, metal and glass material that may be reused or recycled.

In the majority of households and communities, waste is disposed without proper categorization. Waste products can blend into each other, creating a challenge for recycling due to contamination. In addition, this blended contamination creates a higher challenge to waste processing systems because they have to contend with waste of various types. The traditional method for manual waste segregation has historically based on individual workers within the Waste Management Departments to manually separate the waste by types to maintain the integrity of each type of waste during processing and subsequent recycling. While manual waste segregation is effective, it does require a large amount of human input and as such present's potential health hazards to the workers who are manually handling the waste. Additionally, manual waste segregation results in large amounts of unseparated, unsorted waste increases costs associated with waste processors able to provide their customers with an effective waste management and recycling solution. The solution to this type of problem can be found through recent advances in embedded systems and sensor technology used to automate the waste segregation process. Inexpensive microcontroller platforms can automate

a smart Waste Management System through the use of various combinations of sensors, actuators and control mechanisms that can detect the presence of various types of waste, thereby automating the waste segregation process.

An Arduino-based waste sorting system is presented in the research paper that sorts trash as either dry or wet based on a sensor-based detection system. The moisture sensor will scan the moisture level of each waste material and determine whether it is a dry waste or wet waste. After collecting the sensor data, the processing of the sensor data will be performed by an Arduino microcontroller, to operate a servo motor that directs the waste into the appropriate bin. An ultrasonic sensor has also been integrated into the proposed system to check the fill level of the bins and notify the user when the bin is filled. The goals of the proposed system include reducing the amount of manual labor involved in sorting waste, increasing the amount of recycling and creating environmental friendly waste management programs.

2. Related Works

In recent years, waste management has become an important issue due to the increase in people's concern for the environment and the need for commercially sustainable methods of processing waste. Researchers have proposed several innovative technologies to improve the efficiency of how we classify and monitor waste such as Artificial Intelligence (AI), machine learning, computer vision, robotics and the Internet of Things (IoT). The research [1] examined the optimization of solid waste management through a focus on reducing carbon emissions associated with waste processing. Their study provides support for the development of sustainable waste management and effective methods of waste treatment. Similarly, the work [6] compared automated and manual sorting processes for packaging waste to identify opportunities to improve the ways in which we classify waste to maximize recycling.

The use of advanced automation in waste classification has studied in [2] performed a comprehensive survey on the use of robotic systems for sorting of waste in industrial environments. Their work specifically focuses on the processes that robotic technologies will automate for large scale recycling facilities. The work [3] have researched a deep learning model of classifying recyclable waste of convolutional neural networks demonstrating their ability to accurately classify multiple categories of waste material. Other researchers have investigated sensor detection and spectral analysis as methods of identifying waste. The research [4] developed a method for classifying solid waste using hyperspectral imaging. This

method analyses the spectral characteristics of materials to identify the composition of waste. The study [5] completed a review of various image computer vision techniques used in industrial grade waste classification systems and demonstrated that image processing and machine learning techniques could be used to detect recyclable materials.

Recent research has focused on leveraging smart technologies such as IoT and cyber-physical systems to improve waste management. Examples include a comprehensive study [7] outlines these technologies can be used to improve waste monitoring and collection. Similarly, the research [8] developed WasteIQNet, a smart waste management system that uses hierarchical learning & optimization techniques to improve waste classification/management efficiencies. The research [9] used a cyber-physical system to monitor and manage issues by integrating sensor networks and automated environmental monitoring technologies into their wastewater monitoring solution. Another application of smart technologies applied to waste management is through computer vision to identify contamination and categorize waste materials. A good example of this application is mentioned in [10] computer vision-based system for detecting contamination in minimized waste system are increasing detection accuracy of waste within challenging environmental conditions. A second example of computer vision as applied to waste management is the Smart Waste Management System recommended by the work [11] which utilizes artificial intelligence (AI) based algorithms in combination with IoT based sensor technology for improved categorization and monitoring of waste materials.

Researchers have also explored an IoT-based waste monitoring approach. In their study on how to use IoT-based monitoring systems in cities to improve the waste collection process and improve the efficacy of waste management, the work [12] have demonstrated using IoT-based monitoring systems can segregate the waste collection process and enhance the efficacy of waste management in cities. Similarly, they designed a smart waste management unit that utilizes renewable energy and demonstrates that automated waste monitoring can be augmented by using sustainable energy technologies [13]. The system [14] also conducted a literature review to assess a variety of smart waste collection, sorting and recycling solutions. The automation technologies improve the efficiency of the recycling process. The research [15] developed another smart waste management system using IoT to provide increased efficiency to urban waste management systems and to help improve the sustainability of urban waste management systems.

Although the research presented in the above mentioned articles demonstrates that considerable progress has been made in automating waste management in the past few years, many of the proposed solutions depend on very expensive hardware, complex infrastructure or high-computational-cost algorithms. Due to their large size, larger systems may not be practical in homes or schools. Therefore, an economical, efficient, simple embedded system will need to be developed to automate segregating wastes. This is addressed through an Arduino based solution presented by this work.

3. Proposed Work
3.1 System Overview

Using sensors to detect waste materials, automated processing of the waste into wet and dry waste by using microcontrollers, the new system aims to reduce human labor in sorting of waste into the proper container and increase the efficiency of waste recycling by properly categorizing wastes at the time they are generated. The system consists of multiple hardware components including an Arduino Uno microcontroller, moisture sensor, ultrasonic sensor, servo motor and alert mechanism such as a buzzer. These components work together to detect the properties of the waste material, classify the waste type and place the waste into the appropriate bin. When a waste item is placed into the bin's inlet, the sensors measure the properties of the waste. The Arduino microcontroller processes the sensor data to activate the mechanical system components necessary for automatic sorting of the waste. The system also continuously measures the bin's level to ensure that it does not overflow.

3.2 System Architecture

The three modules in the proposed waste system design include: waste detection module, waste separation module and bin monitoring module. Waste detection module has included a moisture sensor which helps measure the moisture content in biodegradable waste material, generating an analog output signal based on the moisture content. The waste separation module is equipped with an Arduino microcontroller and servo motor enabling the system to identify if the waste is wet or dry according to the moisture sensor data provided from the waste detection module. After it sends commands to the servo motor to rotate/redirect the waste into the proper bin. The bin monitoring module has incorporated an ultrasonic sensor to measure the distance of a bin that contains waste and sound an alarm when the bin reaches

its pre-defined capacity. This combined system will allow automatic classification, segregation and monitoring of waste represented in Fig.1.
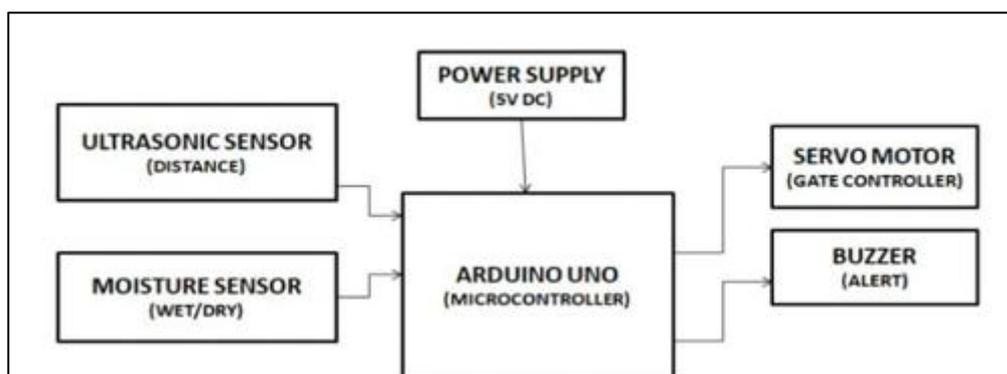

Figure 1. System Architecture

3.3 Principle of Functioning of the System

The System works based on the moisture levels in the waste type. The wet waste content is generally high while the dry waste content is usually compared to the amount of moisture in wet waste. A moisture sensor continually detects the moisture level of the waste as soon as it has been deposited into a bin and sends that data to an Arduino microcontroller. The Arduino compares the sensor's moisture measurement to a pre-defined threshold measurement.

If the moisture measurement exceeds the threshold until the waste is characterized as wet. If the measured moisture is less than the threshold, the waste is characterized as dry. After classification of the waste, the Arduino microcontroller actuates a servo motor assembly to distribute the waste into the appropriate bin. It then returns to the original (starting) position and is ready to act again on an input. In addition, an ultrasonic sensor measures the waste level in the bin. When the ultrasonic sensor measures that the bin is full, an alert is sent to notify the users.

3.4 Waste Segregation Algorithm

The algorithm that outlines the working of the system for automated waste segregation system is as follows.

- Step 1: Start the system and activate all sensors and actuators.
- Step 2: Wait for throwing the waste material in the bin.
- Step 3: Retrieve the value of moisture sensor of waste material.

- Step 4: Compare the sensor reading and predefined threshold value.
- Step 5: In case the value of moisture exceeds the threshold then the waste is considered wet waste.
- Step 6: In case of low moisture value than threshold, the waste is considered dry waste.
- Step 7: The servo motor should be activated to ensure the waste is directed into the correct bin.
- Step 8: Check the level of the bin with sensor of ultrasound.
- Step 9: If the bin is filled to the highest level, the buzzer alarm should turn on.
- Step 10: Put the servo motor back to the default position.
- Step 11: Continue with the same procedure with the subsequent waste input

3.5   System Workflow

This system works with some material has been deposited into the bin, that material enters the system as an input to the waste vessel (bin). The moisture sensor detects the amount of moisture in the refuse and sends that data to the Arduino controller. Next, the moisture reading has been taken by the controller, an evaluation is made in the category of waste material that is being deposited.
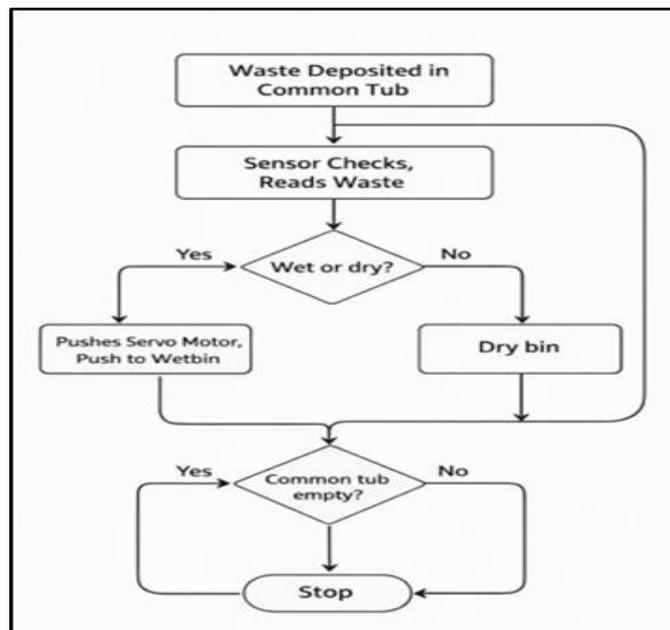

Figure 2. System Work Flow

The position of the servo motor will cause a mechanical gate to be set to either the wet waste bin or the dry. After the waste has been deposited into the bin, the servo motor returns to its original position. At the same time, the ultrasonic sensor measures the total amount of waste in the bin. Once the amount reaches the maximum level, an alert will activate to inform that it is time to empty the bin. The system continues to monitor for incoming waste shown in figure 2.

4. Results and Discussion
4.1 Experimental Setup

The proposed automated sorting system for garbage represented in Fig 3 was implemented using Arduino Uno microcontroller sensor, moisture sensor, ultrasonic sensor, servo motor and buzzer alert module. For the prototype, two trash cans will be used to separately contain wet versus dry. Performance of the automated waste sorting system will be tested by using various types of trash including paper, plastic, vegetable and food waste as examples. Performance of the waste sorting system will test the types of trash detected (dry versus wet) with their corresponding moisture levels. Performance metrics will be provided to the corresponding bin using the servo motor positioning system. It will additionally include real time measurements of volume of contents in each bin with the aid of the ultrasonic sensor. Finally, once the bin is full, a buzzer will notify the user that the bin needs to be emptied.

Figure 3. Experimental Setup of Arduino-Based Automated Waste Segregation System

4.2   Waste Classification Results

The waste products used for tests were soiled in many different materials and moisture readings were recorded for each waste product before being tested.
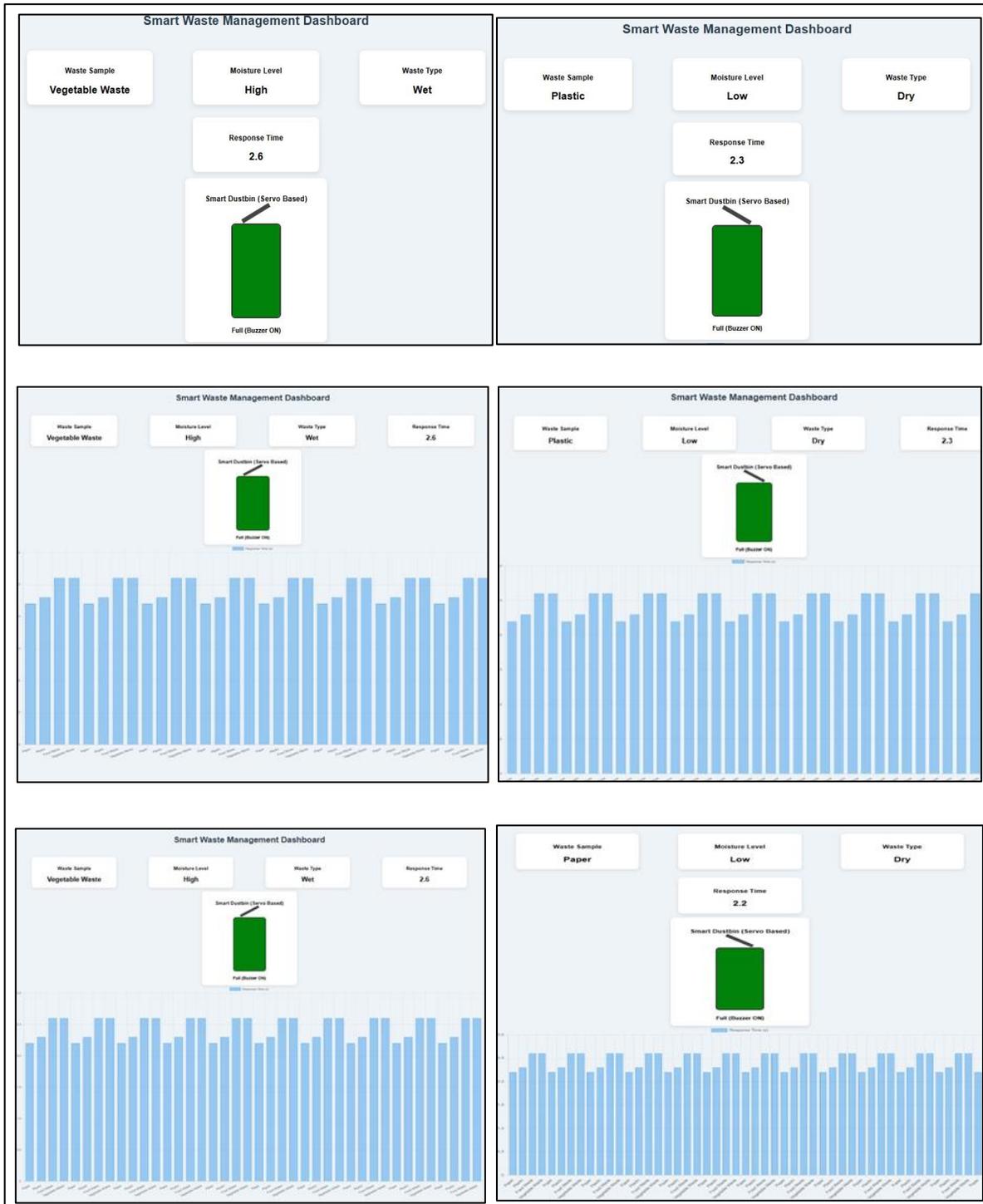

Figure 4. Waste Classification Results Based on Moisture Sensor Readings

Figure 4 depicts the experiment results of waste classification based on the measurement of moisture content using the sensor. Various waste samples were considered in the experiment such as paper, plastic, vegetable waste, food waste and tissue paper. The experiment results show the correlation of moisture content, that the low, medium and high has the classification of waste. It is clearly depicted from the experiment results that waste samples having high moisture content are classified as wet waste, whereas waste samples having low and medium moisture content are classified as dry waste. This depicts the accuracy of waste classification using moisture content. The Table 1 represents the results of all classifications made throughout the experiment. Results indicate that the waste products tested can be classified as either wet or dry based on moisture readings.

Table 1. Waste Classification Findings

Test No	Waste Sample	Moisture Level	System Output
1	Paper	Low	Dry
2	Plastic	Low	Dry
3	Vegetable Waste	High	Wet
4	Food Waste	High	Wet
5	Tissue Paper	Medium	Dry

4.3 System Response Time Analysis

The system's response time is long to identify a given waste type after which the servo motor sends the waste to its correct container. The response times were collected as shown in Table 2. The average elapsed time to complete these 2.3 seconds which is well within a timely manner to segregate waste in an operational situation.

Table 2. System Response Criterion Analysis

Waste Sample	Detection Time (s)	Total Time (s)
Paper	1.2	2.2
Plastic	1.3	2.3
Food Waste	1.4	2.6
Vegetable Waste	1.5	2.6

The response time samples and the variability of response times by actual waste type can be found in figure 5. To summarize, the overall performance level of the system was consistent throughout all test conditions.
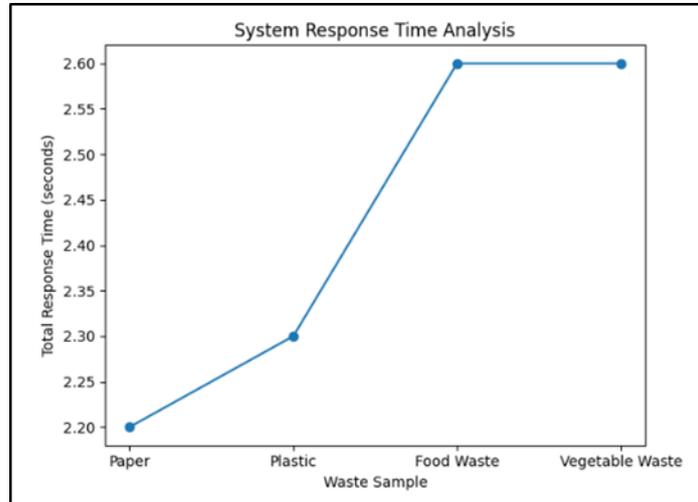

Figure 5. The System Response Time Analysis

4.4 Bin Level Monitoring Performance

The ultrasonic sensor was used to detect the fill level of a waste bin. The sensor was modified to find out where it was located connect the waste surfaces. The results of the bin level detection can be found in table 3. Once the bin reached its level, the buzzer alert system was successfully activated. This activation of the alert system is used to prevent an overflow situation and helps in waste management.

Table 3. Ultrasonic Sensor Bin Level Detection

Distance (cm)	Bin Status
30	Empty
20	Partially Filled
10	Almost Full
5	Full

4.5 Discussion

The proposed Arduino-based automated waste separation solution has been evaluated to confirm it is an effective low-cost option to enhance the waste management system from the

source level. The system successfully uses sensor-based detection and microcontroller-based automation to achieve accurate identification of the type of each waste material, separating into wet and dry categories. The moisture sensor is important in determining the type of waste material by measuring the amount of moisture which is a better indicator for determining whether or not a waste material may be recycled. The waste sample test results from testing demonstrated better repeatability of results for typical waste types of paper, plastic, food and vegetable wastes confirmed that the consistent results for the sensor detection method under normal operating conditions. Additionally, the better classification accuracy, the system also displays useful real-time performance. At roughly 2.3 seconds, the average response time indicates the system can process waste inputs efficiently and with no delay makes it capable of operating continuously in a real-world setting. The use of a servo motor mechanism to ensure comfortably and accurately directed waste into the proper waste bins also minimizes the need for manual intervention. Automating this process highly reduces the amount of human effort involved and improves hygiene through reduced contact between workers and waste materials. Additionally, the ultrasonic-based bin monitor module provides another functionality by accurately monitoring the volume of waste in the bins at all times. The buzzer alert system activates when the bin reaches its full capacity helps to monitor overflow and ensures timely waste disposal contribute to increased efficiency of the waste collection system as a whole.

The accuracy of the classification of waste is dependent on both the calibration of the moisture sensor and the nominal threshold settings which may vary due to changes in environmental conditions. In addition, an importance has been placed on the system being primarily designed for general segregation of waste streams based on the water content (wet or dry). The system was not developed to sort waste streams containing complex and/or multiple kinds of waste is a significant limitation can be processed. In addition to that limitation, one of the main goals of the system is to develop a waste segregation system that would scale the current prototype was designed for small-scale locations. The system will need to be developed using more advanced sensing methods/technologies, more robust mechanical designs/specifications and/or incorporate IoT-based monitoring systems to achieve the implementations of the system to larger scale applications. Overall, the system designed and provide a smart and automated waste management systems. It was designed to include both cost-effectiveness and functionality to provide solutions to the problems associated with waste segregation and to promote sustainable recycling practices. By adding more features to the

current system, the accuracy, adaptability and scalability of the system can improve system in smart cities for large-scale waste management operations.

5. Conclusion

When relate to waste management systems, a waste removal and sorting automated system using Arduino has been both developed and tested to improve on previous solutions and waste materials from the available sources that not have to be separated manually. A sensor detects the presence of a waste product establishes whether it is wet or dry through measuring the moisture levels using a moisture sensor and processing those measurements through an Arduino Uno module which then controls a servo mechanism to direct the waste to the appropriate bin. There is also a secondary ultrasonic sensor fitted to detect the each full bin will sound a buzzer to provide a warning. Testing of the waste sorting system has proven that it is capable of effectively sorting waste at acceptable response times and with high levels of accuracy. The combination of sensors, Arduino control and mechanical actuation will ultimately allow the overall system to operate independently from humans with minimal interaction from individuals. Based on the experiences with the work, this technology is an effective tool in decreasing human labour required and improving new ideas in the recycling process through proper waste separation at the source. The proposed work is affordable and can easily be used at an individual or residential level in a large-scale design such as in schools, homes, offices or small businesses. Over time, the system could be upgraded with IoT capabilities for remote monitoring and advanced sensing and artificial intelligence-based methods of detecting other types of waste including plastics, metals and glass from other areas. Eventually, this capability could enhance the effectiveness of the waste management system and allow for the development of smarter waste management systems.

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