A Review Paper on Smart Waste Segregation Systems (SWSS)

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ABSTRACT

The problem of waste is getting bigger every day because of fast-growing cities, industries, and the way people consume things. Most of the time, waste isn't properly separated at the source, which ends up polluting the environment, creating health problems, and making recycling and disposal more expensive. Doing it the traditional way, by hand, is slow and risky for the workers too. That's why **Smart Waste Segregation Systems (SWSS)** are coming up as a better and smarter solution. These systems use sensors like **infrared, inductive, and moisture sensors**, along with **microcontrollers** such as **Arduino** or **Raspberry Pi**, to automatically detect and sort different types of waste. Some even use image processing and machine learning to make the process more accurate. Studies show that these systems can separate **biodegradable, non-biodegradable, metallic, and recyclable waste** effectively, while cutting down human effort and improving efficiency. In short, SWSS is a big step towards cleaner cities, smart waste management, and a healthier environment.

Keywords - Waste management; Smart waste segregation; IoT; Automation; Sensors; Machine learning; Smart cities; Waste detection

1. INTRODUCTION

With cities growing fast, industries expanding, and populations increasing, the amount of waste being produced worldwide is going up at an alarming rate. Some reports even say that by 2050, the world could be producing more than 3.4 billion tons of waste every year [1]. This puts a huge strain on waste management systems, which are already struggling. Old-school methods like open dumping and landfilling aren't sustainable anymore since they end up polluting the soil, water, and even the air. One of the best ways to tackle this issue is by properly segregating waste right at the source. This not only makes recycling easier but also reduces the overall environmental impact and helps us manage resources better.

Even though people are more aware of waste management today, most systems still depend on manual segregation. This method takes a lot of time, is not very efficient, and can even put sanitation workers at risk of handling harmful waste. On top of that, when waste isn't properly separated, recyclable items often get contaminated, which lowers recycling efficiency and forces us to rely more on landfills and incineration. With the amount of waste only going up, it's clear that current methods aren't enough, and without smart technology, future cities could face major environmental and health problems.

Smart Waste Segregation Systems (SWSS) are seen as a promising solution to this challenge. These systems use sensors, microcontrollers, and IoT-based technologies to automatically identify and separate waste. They cut down human effort, improve accuracy, and even allow real-time tracking through data analysis. The goal of this review paper is to go through the progress made so far in SWSS, look at the different methods and technologies used, and discuss how effective they are along with their limitations. It also highlights how important SWSS can be in building sustainable cities and supporting the bigger goal of smart urban development

2. LITERATURE REVIEW

Many researchers have worked on Smart Waste Segregation Systems to operate the system in their unique ways.

Md. Kishor Morol and his team [2] built an automated waste segregation setup that used a 12-foot conveyor belt, DC gear motor, servo motor, Arduino UNO, and Raspberry Pi for control. They also added a camera module to sort waste into six categories and connected everything to an Android app for monitoring and notifications. When they tested it, the system showed really good results — 92.65% accuracy for plastic, 99.99% for metal, and an overall accuracy of 98.36% on their custom dataset.

In another study, Kapil Dev Sharma et al. [3] designed an automated waste segregation model using AutoCAD to identify and separate dry, wet, and metallic waste. Their system helped cut down on manual work, made waste collection more efficient, and was built as a compact, low-power unit suitable for home use. They also mentioned that in the future, adding things like robotic arms and more advanced sensors could make the system even better.

According to the research by Md. Sohel Rana et al. [4], they used a solar panel and battery for powering their system. For detecting waste, they used an IR sensor, a microcontroller, and a servo motor. To check if the waste was wet or dry, they added a rain sensor to decide which tray it should go into. The microcontroller controlled the servo motor, moving it to +90° or -90° to drop the waste into either the wet or dry bin. They also used an ultrasonic sensor to monitor the fill level of each bin. Once a bin reached 80% capacity, the GSM module sent a notification to the authorities for collection.

In 2022, Rahul Rajendra Pai et al. [5] worked on designing a magnetic drum separator to efficiently sort dry household and institutional waste. Their system could successfully separate plastic, paper, metal, and glass. The magnetic drum achieved very high efficiency, with 98.25% for plastic, 99.88% for paper, and 99.88% for metal. This shows that the device is a highly promising solution for waste management, providing a much more efficient alternative to traditional methods.

According to the research of Mangesh R. Segokar et al. [6], their automated waste segregation system was able to sort household waste into three categories: dry waste, organic waste like vegetable peels, and metal waste. This segregation happened directly at the source and on a small scale, making it more practical and effective for smart cities compared to the usual large-scale collection methods. This is especially useful since households usually produce only small amounts of waste at a time.

In 2024, Kishore R. et al. [7] worked on the importance of waste segregation for both environmental protection and public health. Their system helps with recycling, reduces pollution, preserves resources, and prevents health problems caused by hazardous waste being thrown away improperly. In their setup, they used a moisture sensor to separate wet and dry waste, a servo motor to direct the waste into the correct bin, and an ultrasonic sensor to detect when the bin was full. An Arduino UNO was used to send this information to a computer, and the process paused until the full bin was emptied.

According to the research of Juhi Pandey et al. [8] The Automatic Waste Segregator (AWS) is an affordable, easy-to-use household system designed to sort waste into metallic, dry, and wet categories. It uses Arduino Nano for control, a moisture sensor for wet/dry sorting, and an inductive proximity sensor (metal detector) for metallic waste. The system uses a rotating plate to deposit the categorized waste into separate storage containers. This automation aims to reduce the public health hazards and time consumption of traditional methods while promoting efficient and economic waste management.

According to the research of Sri Krishna Shastri et al. [9] Automatic Waste Segregator (AWS) models are proposed to sort household waste into metallic, dry, and wet categories. One uses an Arduino Nano, moisture sensor, and inductive proximity sensor with a rotating plate. The other uses a microcontroller, inductive proximity sensor, and a high-speed blower to separate dry/wet waste by weight, achieving ≈80% efficiency. Both aim to automate at the source to reduce health hazards and improve efficiency.

According to the research of Aayush Singh et al. [10] Automatic Waste Segregator (AWS) models are proposed for cost-effective household sorting of waste into metallic, dry, and wet (sometimes plastic) categories. These systems use technology like Arduino/microcontrollers with moisture, proximity, capacitive, and rain sensors. The goal is to automate segregation at the source to reduce manual labour hazards and improve recycling efficiency.

3. METHODOLOGY

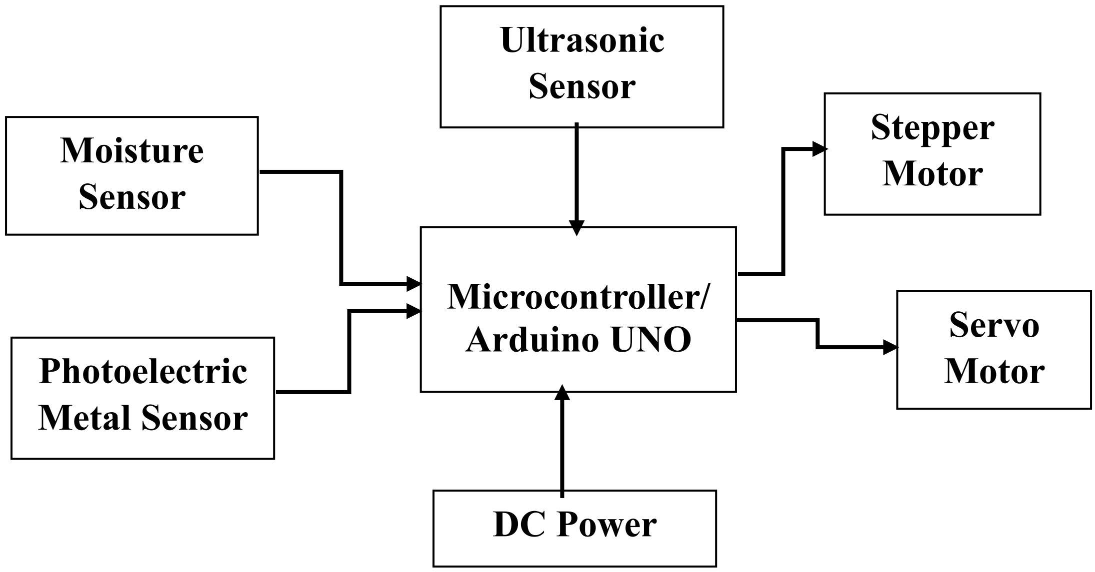

Fig.[a] Block Diagram

The working of a Smart Waste Segregation System (SWSS) usually brings together hardware, software, and communication tech to automatically classify waste. The process can be broken down into a few simple steps:

➢ **Step 1: Waste Collection**

Waste is dropped into a smart bin, which may have multiple input slots or a single chamber. The bin is designed so that the waste passes through sensors for initial checking.

➢ **Step 2: Sensing and Detection**

Different sensors are used depending on the type of waste:

- Inductive sensors to detect metals.
- Moisture sensors for wet or biodegradable waste.
- Infrared or capacitive sensors for dry/non-biodegradable items.
- Cameras with image processing for recyclables like plastic, paper, and glass.

➢ **Step 3: Data Processing**

The signals from sensors or images are sent to a controller such as Arduino, Raspberry Pi, or ESP32. The embedded program then decides the category of the waste. In AI-based systems, machine learning models (like CNNs) are used to improve accuracy.

➢ **Step 4: Actuation and Segregation**

Once classified, the controller triggers actuators or servo motors to push the waste into the right bin. This could be done using a conveyor belt, rotating plate, or flap mechanism. Waste usually gets sorted into biodegradable, non-biodegradable, metallic, or recyclable bins.

➢ **Step 5: IoT Integration and Monitoring**

IoT modules such as Wi-Fi, GSM, or LoRa send live data about the bin's status, fill level, and waste type to cloud dashboards or municipal servers. This makes it easy for authorities to track bins and plan collections.

➢ **Step 6: Data Analytics and Optimization**

The collected data can then be used to study waste generation trends, plan routes for garbage trucks, and maintain bins on time. Some systems even use solar panels to keep the bins running continuously in a sustainable way.

Overall, this setup makes segregation automatic, efficient, and scalable. It reduces human effort while supporting better recycling and cleaner environments.

4. DISCUSSION

The studies reviewed show a variety of techniques for smart waste segregation, ranging from advanced camera-based systems to simple sensor-based designs. For example, achieved an overall accuracy of 98.36% by using Arduino, Raspberry Pi, and a camera module to classify waste into six categories. While the accuracy was impressive, this kind of setup needs more computing power and works best in controlled environments, which makes it harder to use in low-cost applications. On the other hand, created a compact, low-power system that could handle dry, wet, and metallic waste, making it much more practical for home use. This shows the trade-off between high-accuracy AI-based systems and affordable, everyday sensor-based solutions.

Energy efficiency and sustainability are also a big focus in recent research designed a solar-powered model that used IR, rain, and ultrasonic sensors, along with GSM notifications to monitor bin levels. This made the system less dependent on the power grid and more useful in rural or semi-urban areas. Similarly, used moisture and ultrasonic sensors with Arduino to separate wet and dry waste and detect when bins were full. While these systems may not reach the same precision as AI-based ones, they are cheaper, simpler, and easier to adapt for smaller-scale waste management.

Mechanical and hybrid solutions are also being explored to boost efficiency. reported nearly perfect separation of plastic, paper, and metal using a magnetic drum separator, reaching over 99% accuracy. worked on source-level segregation of dry, organic, and metallic waste, which is very practical for smart cities dealing with waste right at the household level. From all these findings, it's clear that no single method is perfect. Instead, hybrid systems that mix the accuracy of AI, the simplicity of sensors, and the strength of mechanical methods—possibly supported by renewable energy and IoT—seem to be the best path forward for future waste management.

5. CONCLUSION

Smart Waste Segregation Systems (SWSS) have a lot of potential for tackling the growing problem of municipal waste. By combining sensors, microcontrollers, IoT, and machine learning, these systems can automatically sort waste into biodegradable, non-biodegradable, metallic, and recyclable categories. Compared to traditional manual methods, SWSS are more accurate, keep people safe from hazardous materials, and make recycling more efficient. Simple sensor-based systems are cheap and work well for small setups, while AI and image-processing systems give higher accuracy for more complex waste. Adding IoT makes it possible to collect real-time data, optimize collection routes, and even predict maintenance needs, which helps smart cities run better.
However, there are still some challenges. High costs, energy use, sensor performance being affected by environmental conditions, and the need for technical skills can make implementation harder. Hybrid systems that combine sensors, and IoT seem like the best scalable and sustainable solution, but more work is needed to lower costs, save energy, and get more people to adopt them. Overall, using SWSS is an important step toward cleaner cities, better resource recovery, and building smarter, more sustainable urban environments.

FUTURE SCOPE

✓ The system can be upgraded to sort more types of waste, like metal, glass, and e-waste, instead of just wet and dry.
✓ IoT can be added so the smart bin sends alerts when it is full, which would make collection faster and more efficient.
✓ Solar power can be used to make the system energy-efficient and eco-friendly.
✓ Cameras and AI image processing could improve accuracy in identifying different kinds of waste.
✓ The system can be made bigger and stronger for public places like railway stations, malls, and busy city areas.
✓ Mobile apps could let people track waste collection and learn the right way to dispose of trash.

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