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Design of an AI Based Robotic System for Waste Sorting

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Abstract: The ongoing economic expansion in many nations is causing a rapid increase in the amount and makeup of solid waste. The waste management system now faces significant challenges in guaranteeing efficient and environmentally responsible solid waste management due to variations in waste quantity and composition. In 2016, the globe produced about 2.01 billion tonnes (BT) of solid trash; by 2030, that amount is expected to rise to 2.58 BT, and by 2050, it will reach 3.40 BT. Only one-fifth of the garbage produced is currently handled; the remainder is disposed of in landfills untreated. When all of the components of solid waste are carefully separated, the maximum economic advantage is achieved. Segregating garbage at the source greatly reduces the complexity of waste treatment facilities. At the home, workplace, college, and industrial sectors, there is no system in place for separating dry, wet, organic, plastic, and metallic garbage. Therefore, the purpose of this study is to design, build, and test an automated trash separation system that is simple to use and reasonably priced for households and small local communities so that waste can be sent straight to waste management facilities. The time and expense of segregation are reduced by this technology, which also reduces human meddling. This system effortlessly divides solid trash into three primary categories— metal, dry, and wet—using an Arduino UNO and a variety of sensors.

Keywords: *Waste Sorting, Smart Waste Management, Smart Bin, Arduino UNO, Automatic Waste Segregation, Sensors.*

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I. INTRODUCTION

In India, about 62 metric tons of solid garbage are produced year, yet most cities do not manage this waste well, which causes major health issues and environmental damage in many places.[1] Although it is unplanned and unregulated, open dumping of rubbish in landfill sites has become a regular waste disposal practice in many Indian towns. India is currently facing numerous difficulties, one of which is inadequate garbage management. Waste segregation and waste-to-energy conversion are the two most challenging aspects of waste management.[2] The environment is seriously harmed by improper waste collection, treatment, transportation, and disposal. Waste production is steadily rising as a result of urbanization, industrialization, and population growth.[3] Numerous researchers have discovered that many Indian cities severely lack the scientific methods for solid waste segregation, collection, transportation, treatment, and disposal, which results in environmental issues and a lower standard of living. Only five states in India are now working on trash source separation; the remaining states continue to dump mixed waste at the same locations. Among the main concerns of waste management are waste treatment methods, recycling and reuse possibilities, door-to-door waste collection, garbage segregation, land availability, and disposal capacity. Solid waste cannot be used productively until all of the recycled garbage has been recycled and the energy from the non-recyclable waste has been recovered. Ragpickers separate rubbish using the old approach, which is still used in the majority of Indian cities. In addition to being inefficient and time-consuming, this approach has a negative impact on the health of those who come into contact with the garbage. People do not separate their waste at home, even in spite of awareness programs. Households and municipalities in such circumstances require an inexpensive and user-friendly method of automatically sorting rubbish. The segregation of waste composition at the source and the application of specified treatment techniques are major components of contemporary solid waste management legislation. To create a clean India, the Indian government started the "Swachh Bharat Mission" campaign. The waste management authority is currently concentrating on the collection and practical separation of waste.[4] Solid waste can be managed using a variety of technologies worldwide, but any effective waste management system must include systematic waste segregation. Solid waste source segregation helps to both boost recycling rates and reduce the quantity of garbage as ends up in landfills. Among the many benefits of the Robotic Waste Segregation and Monitoring System (RWSMS) are the reduction of pollution, the reduction of landfill trash, the abolition of manual work, and the provision of aneconomical, effective, and user-friendly solution.[5] In order to improve

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trash management efficiency, this work attempts to build and create a robotic system that can autonomously classify waste into three categories: dry, moist, and metal.

II. LITERATURE REVIEW

The environment and human health are at risk due to the growing difficulties in waste disposal, segregation, and recycling. Economic expansion, industrialization, and rapid urbanization have all contributed to an increase in trash, making effective waste management crucial.[6] To reduce pollution and safeguard the public's health, proper handling, segregation, transportation, and disposal are essential. Waste can be converted into useful resources instead of being thrown away as waste when it is properly sorted. There aren't many automated waste segregation systems at the industrial level yet. A straightforward yet efficient way to classify waste items like glass, metal, and plastic is to put in place an automatic segregation system. By separating waste into several categories, such a method can increase recycling efficiency. Inductive sensors can be used to identify metallic debris, and capacitive sensors can differentiate between materials like plastic and metal thanks to sophisticated sensor technology. Waste may be treated and recycled more efficiently because to the precise segregation ensured by microcontroller-based automation. Garbage collection and monitoring are another difficulty in waste management. Unsanitary conditions and an increased risk of disease transmission are caused by overflowing trash cans. This problem can be solved by incorporating sensors and real-time monitoring into an intelligent waste management system.[7] The system uses sensors to identify when a bin is full and notify local authorities, allowing for prompt collection and minimizing the need for manual monitoring. To ensure effective resource allocation, garbage collection crews can also receive immediate notifications by connecting the system to a mobile application. Hygiene product waste must also be properly disposed of and recycled. By integrating energy recovery and sterilization, an integrated waste processing system can enhance environmental sustainability.[8] One strategy is to use biological materials to generate energy while separating plastic components using sorting processes. One strategy is to use biological materials to generate energy while separating plastic components using sorting processes. The urgent need for efficient waste management systems is frequently illustrated by the growing amount of waste produced. Energy recovery techniques, automated segregation, and real-time monitoring are workable ways to improve sustainability. These technologies can be used to turn waste into a resource, improving public health and reducing its detrimental impact on the environment. Metal, paper, and plastic are among the waste materials that the sensor fragment can identify. An inductive proximity sensor is used to detect metal garbage, much like it is for paper and plastic waste. The computer and the mechanical component of a servo motor work together to separate the waste types appropriately. The recycle bin prototype is likely to be used in the future, given the work's output demonstrates that it can effectively sort waste, particularly plastic-based waste. However, for efficient trash segregation, the prototype's sensitivity to paper and metal waste needs to be substantially enhanced.

III. METHODOLOGY

Creating a smart dustbin system powered by an Arduino Uno microcontroller is the main approach for creating an automatic dry, waste, and metal segregator. Serving as the central processing unit, this microcontroller decodes information from various sensors and responds by regulating actuators. In order to ensure seamless functioning, it is designed using Embedded C++ in the Arduino Integrated Development Environment (IDE) to effectively handle input and output signals from all connected components. The system uses a variety of sensors designed for waste identification and sorting: metal detectors that use inductive sensing principles to identify metallic objects; moisture sensors that differentiate between wet waste (like organic matter) and dry waste (like paper or plastic) by measuring moisture levels; and ultrasonic sensors that detect the presence of waste and measure its distance from the sensor. These sensors serve as the core of the segregation process and are interfaced with the Arduino Uno. To make sorting waste easier, compartment flaps are actuated by servo motors, which drive waste into bins marked Metal, Waste, and Dry. To ensure precise classification, the Arduino uses real-time sensor inputs to initiate this mechanical movement. To maintain continuous functioning, the system is fueled by a dependable energy source, such as an AC adapter or a 9V battery. To improve motor responsiveness and fine-tune sensor accuracy, extensive testing is carried out using mixed trash samples after the prototype is assembled. A thorough maintenance plan is included in the deployment phase to handle wear and tear, and performance data gathered during operation is examined to improve efficiency. By streamlining resource recovery and ensuring that the segregator efficiently separates waste for recycling or disposal, this iterative optimization helps to promote sustainable waste management practices and lessen environmental impact.

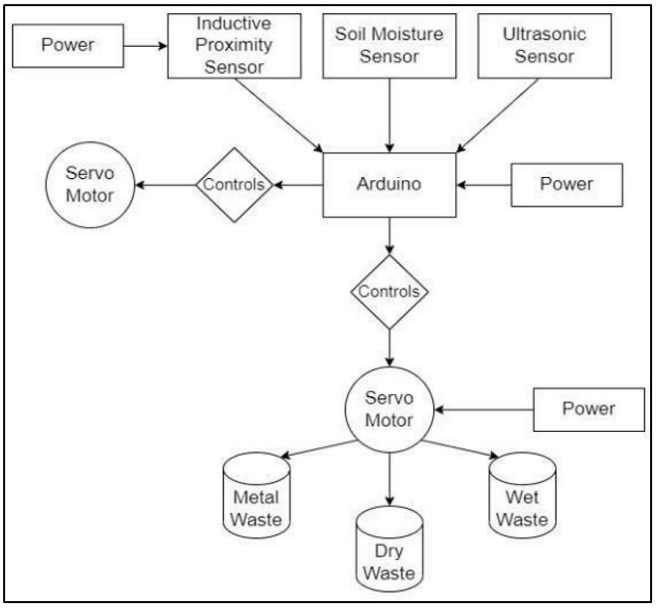

Fig 1 Smart Dustbin System

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IV. COMPONENTS REQUIREMENT

➢ *Arduino UNO:*

Fig 2 Arduino Uno

It is a publicly accessible electronics UNO25,26 framework that works on user-friendly hardware and executable code. The classification of chips and associated controllers installed in it is facilitated by the structure framework of the Arduino board. The Arduino board is equipped with 14 digital pins that can function as either input or output, in addition to 6 analog pins designated for input purposes, facilitating the connection of diverse circuits. Additionally, customizable embedded C and C++ programming codes have also been used in microcontrollers. The Integrated Development Environment (IDE) provided by the Arduino microcontroller which supports different languages of programming. The Arduino board used in the project is programmed using a Universal Serial Bus (USB).

➢ *Servo Motor:*

Fig 3 Servo Motor

It is utilized to dump the garbage into the individual containers. A servomotor can be characterized by an angular motion actuator or a straight motion actuator, designed to facilitate precise control over position, velocity, and acceleration. A suitable motor is connected to a sensor to obtain positional input.

➢ *Rain Sensor:*

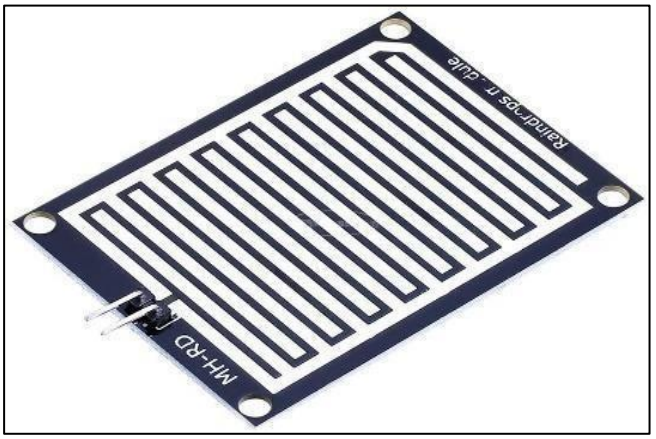

Fig 4 Rain Sensor

It is used to determine the moisture Sensor content of waste by identifying the presence of water within the waste. The presence of moisture content within the waste is sensed and based on this assessment the waste is put into a suitable container.

Fig 5 Inductive Sensor

It is used for the detection of metallic Proximity components without contact. This sensor Sensor 30 does this in a way that is not sensitive to the size or colour of the object. An important property of inductive sensors is that they are cheap and reliable.

➢ *Ultrasonic Sensor:*

Fig 6 Ultrasonic Sensor

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It is used to measure the motion and Sensor 31 distance of any object by using the waves of ultrasonic sound. This sensor uses a transducer that sends and receives ultrasonic pulses to provide information about the proximity of an object. In this project, ultrasonic sensors have been used to measure the filling level of dry, metal, and wet bins.

➢ *Buzzer:*

Fig 7 Buzzer

The buzzer in the waste sorting system acts as an alert device. It sounds when waste is detected, when a bin is full, or if there's a system error. It helps notify users or operators in real time.

➢ *GSM Module*

Fig 8 GSM Module

The GSM module in the system is used to send messages about the status of the dustbins. For example, when a bin is full, the GSM module sends an alert to the operator's phone. This helps in remote monitoring and ensures that bins are emptied on time.

Table 1 Difference between Ultrasonic, Moisture & Inductive Sensor

Features	**Comparative Analysis**		
	Ultrasonic Sensor	***Moisture Sensor***	***Inductive Sensor***
Purpose	Measures distance or bin level	Detects moisture content in materials	Detects presence of metal objects
Working Principle	Uses sound waves	Measures electrical resistance in soil	Uses electromagnetic field
Output Type	Analog/Digital	Analog	Digital
Contact/non-contact	Non-contact	Contact required	Non-contact
Environmental Sensitivity	Affected by temperature, wind	Affected by water and corrosion	Works well in harsh environments

V. WORKING PRINCIPLE

Five sensors are utilized in this system, three of which identify the sort of waste and the other three of which assess if the bin is full or not. Three ultrasonic sensors have been utilized to detect whether or not three distinct bins are full, while capacitive proximity, wetness, and inductive proximity sensors have been used to identify the sort of waste. Wet waste, such as food waste, vegetable and fruit waste, etc., is detected by a moisture sensor; metallic waste, such as copper, aluminum, iron, etc., is detected by an inductive proximity sensor; and dry waste, such as paper, cardboard, plastic, wood, etc., is detected by a capacitive proximity sensor. The sensors identify any thing, such as trash, that is placed into the system's waste hopper unit. The spinning plate detects the object and, if it is dry, brings the dry bin beneath the trash hopper; if the thing is wet or metallic, the dry and metallic bin lets it fall within.

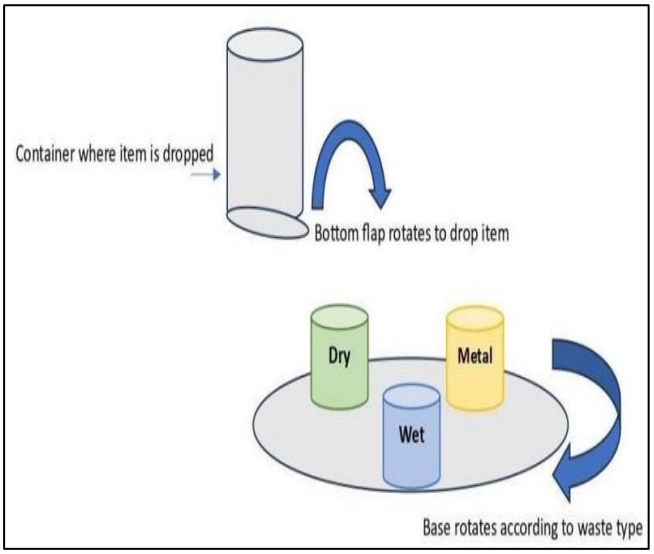

Fig 9 Working Principle

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Relay and servo-motor are used to rotate the plate and ensure that the garbage falls into the bin. The technology also indicates whether the waste is dry, wet, or metallic as soon as it is recognized and sensed. Communication between the workers and the revolving bin is provided by the GSM module. When the bin is full, the cleaning authority receives a notification that "bin is full" thanks to the GSM module.

VI. RESULT

By guaranteeing that only biodegradable items are disposed of in the natural environment, waste segregation greatly reduces pollution and promotes reuse, recycling, and resource recovery. This process safeguards resources forfuture generations and protects public health by sorting 3 hazardous and non-hazardous waste. Additionally, it removes the health risks associated with faulty disposal of toxic, non-biodegradable items. In order to determine whether garbage is wet (such as fruit scraps or vegetable peels) or dry (such as paper, plastic, or cardboard), the clever mechanism of the segregation system is based on a plank that has a moisture sensor. A servo motor is used to precisely transport the waste into the appropriate container. Each bin's garbage level is tracked by an ultrasonic sensor, which notifies the Arduino Uno microcontroller when capacity is reached. After being written in Embedded C++ using the Arduino IDE, the Arduino contacts a computer that is connected to halt the segregation process until the bin is emptied, guaranteeing continuous operation. A metal detector that uses inductive sensing to recognize metallic waste (such as safety pins, aluminum sheets, and tin scraps) and sort it into a different bin is also part of the system, which is powered by a 9V battery or AC adapter. To calibrate sensor accuracy and motor reaction, performance testing was done using a variety of household waste types, including dry, wet, and metal. One waste type at a time is processed by the system, which reclassifies previously wet materials as dry if they lose moisture. The segregator's efficiency was improved by iterative testing, making it dependable for recycling or disposal. This technology-driven strategy supports sustainable waste management by decreasing reliance on landfills and improving resource recovery. It also adjusts to different waste kinds and enhances public health and environmental preservation through automated, systematic segregation that is suited to contemporary requirements.

Fig 10 Resulted Project

VII. DISCUSSION

The results from an AI-based robotic waste segregation system's testing phase indicate how crucial it is to match the system's capacity to the amount of garbage it is designed to handle.[9] The prototype used a mix of sensors (inductive, moisture, and capacitive proximity) and an Arduino Uno microprocessor to reliably classify domestic waste into three main categories: metal, dry, and wet. However, the volume of trash input has a significant impact on segregation efficiency. The system works well for small scale applications, such homes or local towns, processing one kind of waste at a time with minimal input from human beings.[10] However, the system's drawbacks—such as its reliance on a revolving plate and single-item processing mechanism— become increasingly noticeable when waste volume rises.[11] This implies that in order to preserve practicality and environmental efficacy, the system's size and throughput must be appropriate to the waste creation rate of its intended environment. [12] Integrating a preliminary sorting mechanism, like a trommel system, is beneficial for handling mixed trash scenarios that are frequently seen in real-world settings. Heterogeneous trash can be efficiently broken down into individual particles using a trommel, which is a revolving drum encased in a screen.[13] Heterogeneous trash can be efficiently broken down into individual particles using a trommel, which is a revolving drum encased in a screen. During testing, it was found that bigger materials were separated by rotational motion, but tiny waste fragments (such as those that passed through a 300 mm screen) stayed inside the drum. In addition to removing the requirement for manual stirring, this agitation improves the system's capacity to manage intricate waste streams. Additionally, moisture in wet garbage might be eliminated by using airflow through the trommel's drum, which would enable previously moist materials to be reclassified as dry. This flexibility is essential as the moisture content of garbage, especially organic waste like food scraps, frequently changes over time. By include this pre-processing step, the downstream sensors and actuators of the robotic system may concentrate on more precise classification, increasing overall accuracy and cutting down on processing time. This technology has significant social and environmental ramifications. The technology reduces the need for manual labor, such ragpickers, who are subjected to health risks in India's traditional trash management methods, by automating garbage segregation at the source.[14] This change not only increases worker safety but also supports the Swachh Bharat Mission's overarching goals, which place a strong emphasis on sustainable and clean waste management.[15] By carefully selecting waste for recycling and resource recovery, landfill-bound waste is reduced, which further reduces pollution and preserves natural resources. For example, recycling is made easier when metallic waste (such as copper and aluminum) is separated, while composting or energy recovery operations are supported when wet waste (such as biodegradable organic matter) is isolated. Iterative refining of the system, including sensor calibration and motor response, improved its reliability across a variety of household trash kinds, according to testing, making it a useful tool for sustainable urban living. However, expanding this technique beyond small-scale applications still

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presents difficulties. The throughput of the current prototype is limited by its reliance on servo motors and a single revolving plate, which might lead to difficulties with operation in high- waste settings like industrial zones or crowded urban locations. Future versions could address this by implementing conveyor belts or robotic arms, as recommended in the conclusion, to manage higher volumes and more waste streams at once.[16] Furthermore, although the system's sensor suite works well for classifying metal, dry, and wet materials, it lacks the granularity necessary to differentiate between subcategories such as recyclable and non-recyclable materials or biodegradable and non-biodegradable plastics. To overcome this restriction and provide finer segregation that complies with contemporary recycling regulations, the sensor array could be expanded to include infrared or optical sensors. Another level of sophistication is added by integrating real-time monitoring with GSM modules and ultrasonic sensors. The technology effectively alerted operators when bins filled up during testing, avoiding overflow and guaranteeing uninterrupted operation. In smart city settings, where timely waste collection and effective resource allocation are critical, this feature is very beneficial.[17] However, concerns over energy sustainability are raised by the need on an AC converter or 9V battery. This could make deployment more difficult in areas like rural India where power grids are unstable. As suggested in the conclusion, switching to solar power would make the system a truly green technology by lowering operating costs and improving its environmental impact. In contrast to industrial-scale waste management methods, which frequently call for substantial infrastructure and expenditure, this robotic system provides a practical and affordable substitute.[18] Because of its modular construction, it may be customized to meet local demands in homes, offices, or educational settings. 4 However, public acceptance and awareness are key to its success. As mentioned in the introduction, the impact of automated technologies may be diminished if household waste segregation practices are lacking. This gap might be closed by combining this method with community education initiatives that would motivate locals to pre- sort their waste or at the very least comply with the automated procedure.

VIII. CONCLUSION

India, a developing nation with the highest population in the world, produces a significant amount of waste every day. Only 20% of the 62 million tons of MSW produced annually in urban India are handled, while 70% are collected. Since different waste types have varied characteristics, it is not a good idea to discard all of the waste at once because it will be difficult to reuse. Waste segregation is essential to waste reuse. When segregation takes place at the source, waste management is greatly streamlined. As a result, the automated waste segregation strategy described in this work is effective, sustainable, low electricity driven, and requires very little human supervision. When the bin fills up, this system can determine it and notify the staff to come get the rubbish. The collection vans' fuel consumption, collecting time, and labor are all effectively decreased.

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REFERENCES

[1]. Vergara SE, Tchobanoglous G. Municipal solid waste and the environment: a global perspective. Annual review of environment and resources. 2012 Nov 21; 37(1):277 309.
[2]. Izuchukwu Precious O, Zino IO. From Cities to Villages A Comparative Study of Waste Management Policies. World of Semantics: Journal of Philosophy and Linguistics. 2025; 3(2):1- 31.
[3]. Pratapa MG. 10 Electronic Wastes and Its. Electronic Waste: Impact on Health, Animals, and the Environment. 2025 Apr 7:79.
[4]. Mohabuth AQ, Sunnassy NR. Prototyping waste collection by the implementation of a smart bin using AI techniques. In2024 International Conference on Smart Systems for applications in Electrical Sciences (ICSSES) 2024 May 3 (pp. 1-6). IEEE.
[5]. Kazerooni EG. The cities most affected worldwide by water pollution.
[6]. Saher R, Saleh M, Anjum M. Holistic trash collection system integrating human collaboration with technology. Applied Sciences. 2023 Oct 13; 13(20):11263.
[7]. Rashidi Mohammadi A, Petrovic EK, Perkins N. Mapping forestry practices against Sustainable Development Goal targets. Frontiers in Sustainability.; 6:1534449.
[8]. Psakis G, Griffin S, Dimopoulou M, Angelis Dimakis A, Lorenzo JM. Greening the way: Emerging green technologies in process intensification. Frontiers in Chemistry. 2024 Sep 19; 12:1487667.
[9]. Farghali M, Osman AI. Revolutionizing waste management: unleashing the power of artificial intelligence and machine learning. InAdvances in Energy from Waste 2024 Jan 1 (pp. 225-279). Woodhead Publishing.
[10]. Diaz-Elsayed N, Rezaei N, Guo T, Mohebbi S, Zhang Q. Wastewater-based resource recovery technologies across scale: a review. Resources, Conservation and Recycling. 2019 Jun 1;145:94-112.
[11]. Auranen I. Towards waterless operations from mine to mill. Minerals Engineering. 2022 Sep 1;187:107793.
[12]. Duflou JR, Sutherland JW, Dornfeld D, Herrmann C, Jeswiet J, Kara S, Hauschild M, Kellens K. Towards energy and resource efficient manufacturing: A processes and systems approach. CIRP annals. 2012 Jan 1;61(2):587-609.
[13]. Anastassakis GN. Solid Waste Separation and Processing: Principles and Equipment. Handbook of Environmental Engineering. 2018 Aug 3:627-71.
[14]. Raju RD. Waste management in India–an overview.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jun159

[15]. Raju RD. Waste management in India–an overview. Mohapatra G. Projected behavioural change in Swachh Bharat Mission: a public policy perspective. Indian Journal of Public Administration. 2019 Jun;65(2):451-74.
[16]. Bünger L. Robotic waste sorting. Worcester Polytechnic Institute, Worcester, MA, USA. 2021 Apr 6.
[17]. Esmaeilian B, Wang B, Lewis K, Duarte F, Ratti C, Behdad S. The future of waste management in smart and sustainable cities: A review and concept paper. Waste management. 2018 Nov 1;81:177-95.
[18]. Abdullah M, Abedin MZ. Assessment of plastic waste management in Bangladesh: A comprehensive perspective on sorting, production, separation, and recycling. Results in Surfaces and Interfaces. 2024 May 1;15:100221