# Internet-of-Things- and Cloud-Based System for Resource Reclamation

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Contributor: Mithila Farjana , Abu Bakar Fahad , Syed Eftasum Alam , Dr. Md. Motaharul Islam

IoT-based smart e-waste management is an emerging field that combines technology and environmental sustainability. E-waste is a growing problem worldwide, as discarded electronics can have negative impacts on the environment and public health. E-waste refers to repudiated electronic devices, such as computers, mobile phones and other electronic equipment, that are at the verge of their efficacious use.

IoT cloud e-waste pyrolysis resource reclamation

## 1. Introduction

E-waste refers to repudiated electronic devices, such as computers, mobile phones and other electronic equipment, that are at the verge of their efficacious use. Owing to the unrelenting momentum of technological innovation, a growing multitude of individuals are procuring electronic devices with regularity; thus, this begets roughly 54 to 60 million metric tons of e-waste every year, averaging some 7 kg of e-waste per capita. Pursuant to the Global E-waste Statistics Partnership, this is expected to increase to 74.7 Mt by 2030. By 2025, it is estimated that Asia will generate the highest volume of e-waste, at 24.4 million metric tons, followed by the Americas (13.4 million metric tons) and Europe (12.8 million metric tons). Scarcely around 15 percent of global e-waste was collected and recycled in 2014, with the remaining 85 percent being discarded in landfills or incinerated [1].

This situation gives rise to a profound disquietude and engenders a palpable sense of apprehension. It is incumbent upon us to take substantive action. The deleterious effects of electronic waste on the environment are manifold and unequivocal. It has been empirically demonstrated that the materials utilized in the construction of these devices, when containing high concentrations of lead and mercury, are capable of perniciously poisoning the surrounding soil in landfills. Once discarded, the components of e-waste become veritable toxins for the ecosystem, gradually seeping into the earth and causing damage to the atmosphere [2]. This process releases noxious chemicals into the air, thereby exacerbating air pollution. Furthermore, as these toxic materials are carried by rainwater or groundwater, they can affect both terrestrial and aquatic wildlife, rendering e-waste an omnipresent threat to environmental health. The identification and separation of e-waste from municipal solid waste (MSW) is a challenging task that requires significant resources. Moreover, the recycling of e-waste involves substantial costs and requires specialized techniques for sorting and processing [3].

## 2. IoT- and Cloud-Based System for Resource Reclamation

The recycling industry faces a significant challenge in managing e-waste, as there is a pressing need to raise awareness among general people about the environmental and energy-saving advantages of recycling electronic devices. In **Table 1** summary of related works are depicted. Addressing this challenge requires a comprehensive effort to educate users about the benefits of e-waste recycling [4]. Though it is a challenging task, it also presents notable opportunities to effectively navigate this complex field [5]. It requires a multifaceted approach that includes developing environmentally friendly products, effective waste collection, and safe and responsible recycling and disposal. Utilizing a magnetic field to segregate electronic waste into its constituent plastic and metal components represents a sophisticated approach. This method involves applying a magnetic field to the electronic waste, which causes the metallic components to be attracted to the magnet while the non-metallic plastic components remain unaffected [6]. Pyrolysis is an advanced technique that provides a sustainable and efficient solution for plastic parts of e-waste while also reducing the environmental impact of plastic waste [7]. The focus of the research paper [8] was to create an IoT-based monitoring system for e-waste, where they used microcontrollers and sensors to monitor e-waste. One effective strategy for reducing e-waste involves designing products with reusability in mind, inspiring creative reuse across different e-waste sources. Effective intervention strategies should aim to minimize exposure to toxic components in e-waste [9].

Bansod et al. [10] proposed a project that focuses on developing an IoT-based e-waste monitoring system. It utilizes ultrasonic sensors, an Arduino Mega 2560 microcontroller, and GSM communication to detect and monitor e-waste levels in real-time. The main benefits are efficient waste management, reduced overflowing bins, and improved planning of waste pick-ups. The limitations are a reliance on a 12 v source for the GSM module. This project's future work includes potential enhancements like incorporating a line follower robot for automated waste disposal. Bošnjakovic et al. [11] proposed a paper that examines the production of liquid fuel from plastic waste, focusing on technological, ecological, and economic aspects. Pyrolysis with a catalyst, particularly zeolite-based catalysts, is a well-established and mature technology for obtaining fuel from plastic waste. While up to 800 L of fuel can be obtained from one ton of waste plastic, real plants typically yield around 450 L. Disposing of waste plastics through fuel production offers significant environmental benefits, including reduced greenhouse gas emissions. However, waste separation, complex technical systems, and proximity to landfills for cost-effective transportation are limitations.The analysis underscores the large amount of plastic waste in Croatia and the potential for economically viable bio-fuel production with improved waste collection.

**Table 1.** Summary of related works.

| Author and Year | Study Description | Limitations | Method Adopted |
|---|---|---|---|
| Bošnjaković et al. (2022) [11] | Technological and ecological dimensions of converting plastic waste into bio-fuel. | Sorting plastic from e-waste and the cloud; IoT use was not mentioned. | Pyrolysis to turn plastic waste into bio-fuel. |
| Devi et al. (2021) [7] | Emphasis on generating bio-fuels from plastic waste. | No discussion on IoT, the cloud, e-waste | Process of proselytizing plastic waste into diesel fuel. |

| Author and Year | Study Description | Limitations | Method Adopted |
|---|---|---|---|
| | | collection, or plastic-to-bio fuel conversion. | |
| Shamsudin et al. (2022) [8] | IoT-based monitoring system using microcontrollers and sensors. | No discussion regarding the next steps after e-waste collection. | IoT-based project with microcontrollers and sensors. |
| Bansod et al. (2022) [10] | IoT-based system to detect e-waste. | Yet to implement a plan for utilizing the collected waste. | Monitoring garbage levels and communicating them through a GSM system. |
| Balakrishnan et al. (2015) [12] | Investigate the formation of bio-fuels from plastic scrap. | Generating bio-fuels; the methods for plastic collection are missing. | Pyrolysis to convert plastics to bio-fuels. |
| M H, Dinesh. (2020) [13] | Generate bio-oil using pyrolysis. | No mention of collecting plastic from e-waste or another place. | Thermal pyrolysis and catalytic pyrolysis. |
| kazi Shawpnil et al. (2023) [14] | QFD study conducted; combined efficient e-waste management methods. | No mention of the cloud, pyrolysis, bio-char, bio-fuel, or solar batteries. | Physical recycling for metallic parts, the biological method of mycoremediation, phytoremediation. |
| Abdullah Al Mamun et al. (2023) [15] | YOLOv5 to separate e-waste. | Pyrolysis, bio-char, bio-fuel, and solar batteries were not mentioned. | Pixy camera to recognize e-waste. |

[16] d a smart waste management system, which utilizes ultrasonic sensors in bins to measure garbage levels, which are then transmitted to a server via Wi-Fi. The server monitors the bins across the city, notifying the garbage truck driver when the amount of waste in a bin exceeds 70% and it needs to be emptied. SMS notifications are sent to the driver, providing optimized routes based on collected data. Thaseen Ikram et al. [17] proposes a waste management model for smart cities using a hybrid genetic algorithm (GA)–fuzzy inference engine. The system uses IoT components—RFIDs and sensors—to collect and process waste information. The model combines a GA with fuzzy logic to optimize the fuzzy inference system (FIS) and improve waste management accuracy. The system employs cost-effective sensors and ensures reproducibility. Their experimental results show high accuracy and precision of 95.44% in waste management and recyclable item classification. The proposed model reduces errors and minimizes manual interpretation costs compared to traditional approaches, but there could be potential privacy and security risks. Their future work includes integrating advanced technologies and addressing scalability and interoperability challenges. The smart dustbin proposed by Pavithra M. et al. [18] automatically opens upon detecting a clap or foot tap and closes once garbage is disposed of. An ultrasonic sensor monitors the garbage level and sends alerts to the main garbage collector when it reaches capacity. H. Cai et al. [19] proposed a garbage monitoring system where they use a NodeMCU chip integrated with ultrasonic sensors to measure waste levels in bins, which are transmitted to a cloud server through the Ali-cloud IoT platform. To observe the real-time bin status, they have used a web page. The average number of cleanings before establishing this was 3 and afterwards it was 2.28; the average number of bin overflows before was 0.67 and afterwards it was 0.11, which added improvements in waste collection. The paper by Artang Sara et al. [20] introduces a tracking and tracing platform, which offers a

user interface for users and administrators, providing essential information to users for the disposal of their e-waste. Integrating block-chain technology and circular economy approaches into the tracking platform and conducting comparative studies among different countries is their proposed future work.

**Table 2.** In-depth analysis of related works in relation to the benefits and risks of each approach.

| Reference Paper | Limitations | Method Adopted | Benefits | Risk | Future Work |
| --- | --- | --- | --- | --- | --- |
| [16] | Focuses on data collection and monitoring without data analysis for process optimization. | Bins with ultrasonic sensors measure garbage levels, send data to a server via Wi-Fi, and optimize collection routes using SMS. | Direct message sending reduces the costs and maintenance for the embedded bins, enhancing independence and transparency. | The reliance on Wi-Fi and server stability poses a risk of data loss and potential failure in communication. | Incorporating a database and utilizing data analytics to optimize waste management processes and improve efficiency |
| [17] | Limited applicability may impact its practicality in different waste management contexts. | An IoT and fuzzy inference system with a genetic algorithm to create a waste disposal system | Enhanced waste management efficiency, cost reduction, and resource optimization | Reliability, accuracy, privacy, and security | The integration of additional advanced technologies, scalability, and interoperability |
| [18] | Foul odors emanating from the bins and the manual control of the dustbins can restrict mobility and flexibility in waste collection. | Uses sensors for gesture detection and garbage level monitoring, enabling automatic bin operation and timely emptying through an IoT web interface | The automated waste management system reduces labor costs and enables the timely disposal of garbage to the correct location. | The system relies on the accuracy and reliability of the sensors to detect the garbage levels. False readings could impact the efficiency. | The system contributes to waste reduction, resource conservation, and sustainable waste management by handling both metal and non-metal waste. |
| [19] | Alerts cleaners based on threshold parameters but does not differentiate the | A sensor-based device detects and monitors the garbage status and sends notifications to | The notification system eliminates the need for continuous monitoring, as it alerts the | The device might get damaged while using the dustbin as it is set in quite an unprotected manner. | An Android app will be developed for this in future and a better algorithm will be implemented here. |

| Reference Paper | Limitations | Method Adopted | Benefits | Risk | Future Work |
|---|---|---|---|---|---|
| | recycling of e-waste | cleaners when thresholds are exceeded. | cleaner when the dustbin requires cleaning. | | |
| [20] | The limited waste registration and complex interface may impede tracking and user adoption in the application. | E-waste registration, QR code tracking, and Google API integration enable effective monitoring and proper disposal. | The stakeholders can track e-waste and its location effectively through unique identification, facilitating easy monitoring. | The only risk is the security issue as the users are giving certain mobile access via this application. | Create a sustainable system with robotics and blockchain for enhanced security and tracking capabilities. |