

Systematic Literature Review on Machine Learning Deep Learning and IOT-based Model for E-Waste Management

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Abstract: This article provides a comprehensive review of existing research on machine learning, deep learning, and IoT-based models for smart e-waste management. The main objectives are to support research, facilitate other researchers in finding relevant studies, and propose future research areas within this domain. Additionally, it offers stakeholders, organizations, and government bodies valuable insights into smart e-waste management based on research-driven knowledge of implementation strategies. The review results indicate that the most frequently studied areas are motives, critical success factors, implementation status, and benefits. Each of these areas would benefit from further exploration.

Keywords: Machine Learning, Deep Learning, IOT, e-waste, Environment Health

1. Introduction

The article provides summaries of various research articles that explore different aspects of sustainable electronic waste management [1]. The studies focus on the development and implementation of innovative technologies, such as intelligent sorting equipment, sensor-based systems, Internet of Things (IoT) applications, and machine learning algorithms, to improve the efficiency, accuracy, and sustainability of e-waste management processes.

Some of the strengths highlighted in the summaries include the potential for improved sustainability and efficiency in the recycling process, reduction in labor costs, real-time monitoring and data collection, and integration with cloud technology for information sharing and decision support [2-3]. However, the research also identifies certain research gaps and areas for future work, such as the lack of experimental validation or real-world implementation in some studies, the need for detailed discussions on scalability and adaptability, challenges related to training and validation of machine learning models, and the need to address environmental and social impacts of e-waste management [4-8].

E-waste, electronic waste, e-scrap and end-of-life electronics are terms often used to describe used electronics that are nearing the end of their useful life, and are discarded, donated or given to a recycler [9-10]. The UN defines e-waste as any discarded products with a battery or plug, and features toxic and hazardous substances such as mercury, that can pose severe risk to human and environmental health [11-15]. According to the UN, in 2021 each person on the planet will produce on average 7.6 kg of e-waste, meaning that a massive 57.4 million tons will be generated worldwide. Only 17.4% of this electronic waste, containing a mixture of harmful substances and precious materials, will be

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recorded as being properly collected, treated and recycled. Many initiatives are undertaken to tackle this growing concern, but none of them can be fully effective without the active role and correct education of consumers [16-20]. E-waste can be toxic, is not biodegradable and accumulates in the environment, in the soil, air, water and living things. For example, open-air burning and acid baths being used to recover valuable materials from electronic components release toxic materials leaching into the environment. These practices can also expose workers to high levels of contaminants such as lead, mercury, beryllium, thallium, cadmium and arsenic, and also brominated flame retardants (BFRs) and polychlorinated biphenyls, which can lead to irreversible health effects, including cancers, miscarriages, and neurological damage and diminished IQs.

Overall, the theoretical background of the article highlights the importance of developing and implementing smart, automated, and efficient systems for electronic waste management, while also addressing the broader environmental and social implications of these technologies. The studies suggest future research directions, including the implementation of advanced technologies, optimization techniques for waste collection, integration of blockchain technology for secure transactions, and the development of sustainable e-waste management models. The research papers mentioned in the description employ various methodologies and approaches to address different aspects of electronic waste (e-waste) management [21-24].

The remaining paper is organized as follows. Section 2 presents the literature, Section 3 presents the research questions, Section 4 presents the method, Section 5 presents the findings and lastly in Section 6 the conclusions are presented.

2. Review of literature

Several research work and model have been implemented attempting to find out the major key to successfully manage e-waste components and to address the challenging issues.

Ilaria Barletta et al. (2015) [1]: The study developed intelligent sorting equipment for e-waste

management, which improved sustainability and efficiency in the recycling process. Research gaps include lack of explicit mention of the specific methodology used and lack of addressing social sustainability issues. Future work includes implementation of automated sorting equipment, data compilation, decision support, and addressing social sustainability issues.

Mahipal Singh Sankala et al. (2016) [2]: The study reviewed existing literature on the impact of electronic waste on environmental and human health. It emphasized the need for proper e-waste management and suggested possible solutions and strategies. Research gaps include the lack of original research or data. Future work includes advocating for more efficient and sustainable e-waste management practices.

Rashmi (2016) [3]: The study proposed an automated waste segregation system using sensors and a PLC-based system. It highlighted advantages such as modular design, flexibility, cost-effectiveness, and less wiring. Research gaps include the lack of experimental validation or real-world implementation of the proposed system. Future work includes implementing a robotic arm and PLC interconnected with sensors for material detection and addressing sensors' placement.

Debajyoti et al. (2018) [4]: The study presented an IoT-based waste management system monitored by the cloud. It utilized smart waste bins with ultrasonic-level and gas sensors, cloud technology, and a mobile app for monitoring and conveying information. Research gaps include the lack of details on the methodology and validation of the system, and the case study was limited to a specific city. Future work includes using special cameras for waste recognition and implementing appropriate decisions.

Nkolika et al. (2019) [5]: The study developed a smart, automated waste management system using a modified form of the waterfall and prototyping methodology. It implemented features such as lid opening and closing, SMS alerts for the disposal truck driver, and demonstrated practical application. Research gaps include the lack of detailed discussion on scalability and adaptability to different waste management scenarios. Future work includes

integrating advanced technologies like machine learning algorithms for predictive waste collection and optimization.

Kai et al. (2019) [6]: The study developed smart electronic waste collection systems using IoT technology. It utilized smart collection boxes, a backend server, and a mobile application for data recording and notifications. Research gaps include potential unreliability of the ultrasonic sensor used for level measurement and the use of low-cost sensors resulting in false readings. Future work includes implementing mobile applications, data collection systems, and IoT frameworks to enhance the system's capabilities.

Ajay et al. (2020) [7]: The study focused on automatic waste segregation and management using a microcontroller and various sensors. It highlighted the use of different sensors for accurate detection and sorting of waste. Research gaps include the system's limitation to segregate waste into wet, metal, and dry categories and not handling more specific waste categories or hazardous waste. Future work includes implementing robots equipped with AI for efficient sorting.

Dinesh (2020) [8]: The study proposed using thermal pyrolysis and catalytic pyrolysis to extract bio-oil from waste plastic. It discussed the cost-effectiveness of using bio-oil to minimize reliance on hydrocarbons and address environmental issues. Research gaps include the lack of mention of collecting plastic from e-waste or other sources. Future work includes designing the pyrolysis reactor for mixed waste plastics and small to medium-scale development.

Ali (2020) [9]: The study proposed an IoT-based waste monitoring and collecting system for a smart city. It utilized sensor units, a microcontroller, and a GSM module for IoT-based waste monitoring and communication. Research gaps include the time required for GPS module initialization, fluctuation in GPS data, and occasional poor network connectivity affecting message transmission. Future work includes implementing a real-time clock with a timestamp, developing an Android app with a locator, and integrating a grinder with the wet waste bin.

Inna et al. (2020) [10]: The study proposed an IoT-based e-waste management system that involves an android mobile application, e-waste bins or trucks locator, and a pay-as-you-throw system. It incentivizes proper disposal of electronic waste. Research gaps include the lack of discussion on the cost and scalability of implementing the proposed system and the feasibility and effectiveness in real-world scenarios. Future work includes developing machine learning algorithms for waste prediction and implementing blockchain technology for secure transactions.

Tejashree Kadus et al. (2020) [11]: The study proposed a smart waste management system using IoT, AI, and robotics. It aimed to automate the hazardous and labor-intensive process of e-waste collection and segregation. Research gaps include the lack of specific details on the training and validation of AI algorithms for waste identification. Future work includes increasing the payload capacity of the robot for collecting larger appliances.

Khalid et al. (2022) [12]: The study proposed a behavior-based swarm model using a fuzzy controller for route planning and e-waste collection. It effectively optimized e-waste collection and minimized costs. Research gaps include the focus on technical aspects without extensively discussing broader environmental or social impacts of e-waste. Future work should focus on the environmental and social impacts of e-waste management.

Byfield (2021) [13]: The study proposed an automated system for recycling waste from electrical and electronic equipment using mechatronics and machine learning. It highlighted the potential of efficient component removal. Research gaps include the lack of detailed information on the specific technologies and processes used. Future work includes integration of more advanced machine learning algorithms and computer vision techniques for enhanced efficiency and accuracy.

Nurul et al. (2021) [14]: The study proposed an IoT e-waste monitoring system to support smart city initiatives. It utilized Agile methodology for flexible and adaptable development. Research gaps include the risk of scope creep or feature creep due to the iterative nature of the methodology. Future work includes

improving the system's user-friendliness with push email and developing an Android app.

Tanvi et al. (2021) [15]: The study implemented an e-waste vending machine using machine learning technology. It aimed to reduce manual work, promote sustainable e-waste management, and increase social awareness. Research gaps include the need for proper training and maintenance of the machine learning model and potential issues with accurate classification of e-waste. Future work includes improving accuracy and efficiency of the machine learning model and expanding implementation of e-waste vending machines.

Shreyas et al. (2021) [16]: The study applied AI and robotics to enhance the collection and segregation of e-waste in India. It aimed to automate the hazardous process and relieve laborers from their hazardous lifestyle. Research gaps include the lack of specific details about training and validation of AI algorithms for waste identification. Future work includes increasing the payload capacity of the robot for collecting larger appliances.

Bilal (2021) [17]: The study proposed an automated system for recycling e-waste using mechatronics and machine learning. It highlighted the potential of efficient component removal. Research gaps include the lack of detailed information on the specific technologies and processes used. Future work includes integrating more advanced machine learning algorithms and computer vision techniques for enhanced efficiency and accuracy.

Kuldeep et al. (2021) [18]: The study designed and implemented an IoT-based collection vending machine for e-waste management. It utilized Arduino Uno, sensors, Bluetooth module, motor, motor driver, and an obsolete mobile. Research gaps include the requirement for IoT infrastructure for implementation. Future work includes implementing Blockchain technology for safe data storage and secure data exchanges.

Bansod et al. (2022) [19]: The study proposed an IoT-based smart e-waste management system. It aimed to monitor garbage levels and communicate them through a GSM system. Research gaps include the yet to implement a plan for utilizing the collected waste.

Future work includes modifications and improvements to the E-Waste monitoring system, such as adding new functionalities like a line follower robot.

Saidia et al. (2022) [20]: The study utilized a transformer-based machine learning approach for sustainable e-waste management. It applied mixed efficiency approaches, comparative policy analysis, and data analysis techniques for analyzing e-waste management systems. Research gaps include the lack of a clear framework that combines e-waste management and urban sustainability. Future work includes optimizing engines for maximizing performance and efficiency of biofuels derived from plastic waste.

Cai (2022) [21]: The study proposed an IoT garbage monitoring system for effective garbage management. It used a sensor-based device to monitor garbage status and send notifications to cleaners when thresholds are exceeded. Research gaps include the lack of differentiating the recycling of e-waste. Future work includes developing an Android app and implementing a better algorithm.

Ajay Kumar et al. (2023) [22]: The study developed an efficient fill-level monitoring system for smart e-waste recycling. It utilized an ultrasonic sensor as the primary sensor for measuring fill level and a temperature sensor for monitoring bin temperature. Research gaps include the system's lack of GPS module for bin location tracking. Future work includes developing predictive maintenance capabilities based on historical fill levels and usage patterns.

(Perfectson, 2023) [23]: The study focused on discarded computers in Benin City, obtained discreetly from various sources, and conducted a survey to understand user preferences before disposing of used computers. The objectives of the paper are to identify factors for effectively cleansing hard drives before disposal, conduct a survey on data security of e-waste, and design a data security framework for e-waste management. The limitations of the paper include not addressing data security in e-waste, the absence of a recycling center in the county and inadequate technical information. The research gap in this paper is the lack of emphasis on data security in e-waste management, which is a critical aspect that needs to be addressed.

(Perfectson, 2024) [24]: The methodology includes a cross-sectional research design and the administration of structured questionnaires. The objectives of the paper are to identify challenges in e-waste management in African nations. Limitations include the reliance on self-reported data and the use of a single location for the study. Strengths lie in the empirical study conducted with a large sample size. Research gaps include the need for future studies on intelligent recycling systems and sorting technology. The future of this paper lies in proposing a framework to enhance and improve the process of e-waste management and data security, ultimately contributing to better environmental practices and data protection.

3. Research questions

This systematic literature review reveals that existing research is dominated by a few research questions:

- a. Can intelligent sorting equipment improve sustainability and efficiency in electronic waste management?
- b. What are the environmental and human health effects of electronic waste, and what are possible solutions for proper e-waste management?
- c. Can an automatic waste segregation system driven by microcontrollers and sensors accurately sort different types of waste?
- d. Can an automated e-waste vending machine using machine learning technology improve e-waste disposal and reduce incorrect disposal?
- e. Can the application of AI and robotics enhance household e-waste collection and segregation?
- f. Can an IoT-based smart e-waste management system help monitor e-waste levels and improve public sanitation?
- g. Can an IoT-based smart e-waste management system reduce overflowing e-waste bins and improve public sanitation?
- h. Can a smart e-waste management system utilizing IoT and deep learning approaches improve e-waste identification and categorization?
- i. Can an IoT-based automated smart waste management system reduce labor costs and improve timely garbage disposal?
- j. Can an intelligent waste management application using IoT and a genetic algorithm optimize waste disposal?

4. Method

This study is a systematic literature review. A systematic literature review is a rigorous review of research results. The two main objectives for this review are: to identify, classify, and summarize existing research on machine learning and IoT-based model for smart e-waste management and to identify areas and opportunities for future research. The steps in the systematic literature review method are documented below.

5. Findings

The article synthesizes research on the use of machine learning, deep learning, and IoT technologies to address the challenges of e-waste management. Key findings include the identification of several technological advancements that improve the efficiency and sustainability of e-waste management processes. These include intelligent sorting equipment, sensor-based systems, and IoT-based smart waste management systems that enhance real-time monitoring, optimize waste collection, and reduce labor costs. The review highlights that machine learning algorithms have been pivotal in developing predictive models for timely disposal and processing of e-waste. IoT-based systems have shown promise in improving public sanitation by preventing overflowing waste bins and facilitating better connectivity and communication in waste management.

However, the article also identifies significant research gaps, such as the need for more experimental validation and real-world implementation of the proposed systems. It emphasizes the importance of addressing social sustainability issues related to e-waste management, such as the impacts on workers and communities near disposal sites. Additionally, the potential of advanced technologies like blockchain and genetic algorithms in enhancing waste management systems is recognized, but their practical integration remains underexplored. The findings suggest that while substantial progress has been made in leveraging machine learning and IoT for e-waste management, further research is needed to validate these

technologies experimentally, explore their social impacts, and enhance their scalability and adaptability for broader application.

5.1 Discussion

In this section, we analyze and discuss present research in order to identify knowledge gaps and opportunities for future research. The article offers a thorough review of the current research landscape on the use of machine learning, deep learning, and IoT technologies in managing electronic waste (e-waste). It effectively compiles a broad array of studies, providing valuable insights into the various technological implementations, such as intelligent sorting equipment, sensor-based systems, and IoT applications. The article highlights the practical benefits of these technologies in improving efficiency and sustainability in e-waste management, making it a significant resource for researchers in this domain. Despite its comprehensive coverage, the article identifies several critical research gaps. Many of the reviewed studies lack detailed experimental validation and real-world implementation, limiting the assessment of their practical effectiveness. Additionally, the article notes the need for more in-depth exploration of social and environmental impacts associated with e-waste management, including the effects on workers in recycling facilities and communities near disposal sites. These areas require further investigation to develop more holistic and sustainable e-waste management practices. The article also points out redundancy in some of the reviewed studies and emphasizes the need for innovative contributions that stand out. It suggests that future research should focus on integrating advanced technologies such as blockchain for secure transactions and genetic algorithms for optimizing waste collection routes. Moreover, addressing challenges related to scalability and adaptability of these smart systems across diverse geographical and socio-economic contexts is crucial for their widespread adoption and effectiveness. While the article provides a valuable overview of the intersection between machine learning, deep learning, and IoT in e-waste management, it also underscores the necessity for future research to validate these technologies experimentally, explore their social impacts more thoroughly, and enhance their scalability and adaptability. By addressing these gaps, the field

can move towards more efficient, sustainable, and socially responsible e-waste management solutions.

5.2 Some suggestions for future research based on this study could include

- a. Detailed methodology and validation of intelligent sorting equipment: Future research could focus on providing explicit details about the specific methodology used in the development of intelligent sorting equipment for e-waste management. This can include a comprehensive description of the sensors, data processing techniques, and decision support algorithms used. The validation of the equipment's performance and efficiency can also be investigated through experimental studies and real-world implementation.
- b. Implementation of automated sorting equipment for different waste types: While the study focuses on intelligent sorting equipment for e-waste management, future research can explore the implementation of similar equipment for other waste categories, such as plastic, organic waste, or hazardous waste. This can involve the development of specialized sensors and algorithms to effectively detect and sort different types of waste.
- c. Addressing social sustainability issues in e-waste management: The study notes the need for addressing social sustainability issues in e-waste management. Future research can focus on understanding and mitigating the social impacts of e-waste management practices, such as the impacts on workers in recycling facilities, the informal sector engaged in e-waste recycling, and the communities living near e-waste disposal sites. Strategies for improving social equity, worker safety, and community engagement can be explored.
- d. Integration of advanced technologies in waste management systems: Many of the studies mentioned in the research gaps can benefit from the integration of advanced technologies. For example, the use of cameras, machine learning algorithms, and blockchain technology can enhance waste recognition, prediction, and secure transactions in waste management systems. Future research can

focus on developing and evaluating the implementation of these technologies in waste management processes.

- e. Scalability and adaptability of waste management systems: Several studies mentioned the need for discussing the scalability and adaptability of waste management systems. Future research can investigate the scalability of intelligent sorting equipment, IoT-based systems, and other waste management technologies to different scenarios, environments, and waste management contexts. This can involve conducting pilot studies and evaluating the feasibility and effectiveness of these systems in real-world settings.
- f. Optimization of waste collection routes and processes: Many studies mentioned the use of advanced technologies, such as machine learning algorithms and genetic algorithms, for optimizing waste collection routes and processes. Future research can focus on developing and evaluating optimization techniques that consider factors such as waste volume, traffic conditions, proximity to processing facilities, and environmental impacts. This can contribute to improving the efficiency and sustainability of waste collection and transportation.
- g. Environmental and energy benefits of waste management systems: Several studies mentioned the potential environmental and energy benefits of implementing various waste management systems. Future research can focus on quantifying and assessing these benefits through life cycle assessments, carbon footprint analyses, and energy efficiency evaluations. This can provide valuable insights into the environmental impacts of different waste management practices and help in making informed decisions towards a more sustainable future.
- h. User-friendly interfaces and accessibility: Some studies mentioned the need for user-friendly interfaces, mobile applications, or better connectivity in waste management systems. Future research can focus on designing and evaluating user-friendly interfaces, mobile applications, or low-power wide area network

(LPWAN) technologies to increase accessibility and usability of waste management systems. This can help in overcoming challenges related to user adoption, communication, and connectivity in different locations and contexts.

We examined the convergence of deep learning, machine learning, and Internet of Things (IoT)-based models for e-waste management in this systematic literature review, showcasing the creative advances achieved in this field. The study summarized results from multiple studies, demonstrating how these technologies have been applied to address the expanding problem of e-waste management, an urgent environmental and public health concern.

Enhancing the effectiveness and sustainability of e-waste management procedures has been demonstrated to be possible through the integration of sensor-based systems with intelligent sorting equipment. These systems improve waste segregation accuracy and labor costs by enabling real-time monitoring and optimization of waste collection. Developing predictive models that help with the timely processing and disposal of e-waste has been made possible in large part by machine learning algorithms in particular, by implementing IoT-based smart waste management systems, it is now possible to monitor e-waste levels more effectively, which improves public hygiene and lowers the frequency of overflowing waste bins. Additionally, these technologies provide improved communication and connectivity across many places, which help to create waste management solutions that are more efficient and approachable. Even with these developments, the evaluation found a number of research gaps that offer chances for more study in the future. Notably, in order to evaluate the suggested systems' scalability and adaptability in various environmental and waste management contexts, further thorough experimental validation and practical usage are required.

6. Conclusion

The integration of machine learning, deep learning, and IoT in e-waste management holds substantial potential for revolutionizing the field. By addressing the identified research gaps and continuing to innovate, these technologies can contribute significantly to sustainable environmental practices

and improved public health outcomes. Future research efforts should focus on refining these technologies and exploring new applications to maximize their impact on e-waste management system.

Conflict of interest

The authors declared "No conflict of interest".

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