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Research Article

ENVIRONMENTALLY RESPONSIBLE INNOVATIVE TECHNOLOGIES FOR BIOMEDICAL WASTE MANAGEMENT: IMPLEMENTING MACHINE LEARNING CLASSIFIERS AND IoT TRACKING

***Said El Najjar**

Department of Environment, Indian Institute of Industry Interaction Education and Research, Tamilnadu, India

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Abstract

Biomedical waste management (BMWM) is necessary to control the spread of infectious debris. The health care organizations must disinfect, dispose and segregate waste properly. Therefore, new technologies must be implemented to dispose of biomedical waste (BMW) properly. The current study aimed to implement innovative methods to treat bio-medical waste using waste treatment technologies. A qualitative method was used to determine the existing practices in the disposal of BMW and to check hospital workers' knowledge of the biomedical waste recycling process. The images of COVID waste that were collected waste were classified and sorted to be recycled. A support vector machine (SVM) classifier and fuzzy-based system were used for categorizing the waste, and an IoT server was used to track it. The IoT-based monitoring system observes indoor, outdoor, and hazardous materials. RFID technology was used to monitor indoor waste, and GPS was used to collect outdoor waste. The study results showed that the recycling process is necessary in hospitals to treat BMW. Findings also show that the SVM classifier achieved specificity, sensitivity, and accuracy of about 95.9 %, 95.3 %, and 96.5 %, respectively. The medical waste is documented, tracked, located, scanned, and labeled using an IoT tracking device. Implementing these technologies in BMWM helps minimize waste and ensure proper waste disposal. Locating and monitoring more types of waste and separating them using IoT service systems ensures adequate segregation.

Keywords: Biomedical Waste Management; Machine Learning; Support Vector Machine; Fuzzy Systems, Internet of Things (IoT).

INTRODUCTION

Medical waste management (MWM) was considered a significant issue after exposure to hepatitis B (HBV) and human immunodeficiency virus (HIV) during the 1980s and 1990s (Kannadhasan & Nagarajan, 2022). The question was also raised on the risks ingrained in medical waste. Consequently, due to its multidimensional ramifications, hospital waste generation has become a fundamental concern. It is considered a risk to the health of the hospital staff and patients and expands past the frontier of establishing hospitals to familiar people (Salvia *et al.,* 2021).Medical waste as the material produced after the treatment, diagnosis, and immunization in biomedical research and on patients is called hospital waste (Pandey *et al.,* 2016). Biomedical waste (BMW) is built in veterinary institutes, animal houses, blood banks, laboratories, healthcare teaching institutes, hospitals, clinics, and research institutions (Kalia *et al.,* 2020). Considerably, proper regulations must be carried out to dispose of medical Waste. The rules and regulations were recommended by the Centre for Disease Control (CDC) and the American Dental Association (ADA)(Reddy *et al.,* 2019). In India, MWM mainly focuses on the BMW (Management and Handling) Rules, 1998, which the Ministry of Environment and Forest declared(BMW Management and Handling, 1998). The rules make it compulsory for medical establishments to dispose of, disinfect, and segregate their waste in an environmentally friendly way(Sharma *et al.,* 2013).The issue of BMW became more complex when syringes were reused without proper sterilization, handling unprotected medical waste without wearing shoes, masks, and gloves and especially during the recycling process (Sharma *et al.,* 2013).

Corresponding Author:** ***Said El Najjar,
Department of Environment, Indian Institute of Industry Interaction Education and Research, Tamilnadu, India.

Due to the use of unsterilized syringes, 240 people in India were affected with hepatitis B in 2009 (Selvan Christyraj *et al.,* 2021). International Clinical Epidemiology Network inspected the existing BMW practices, such as the framework and setup of primary, secondary, and tertiary medical facilities available in twenty states during 2002-2004 (Datta *et al.,* 2018). The investigation results showed that the health care facility at the tertiary level was 54%, the secondary level was 60%, and the primary level was 82%, but had no dependable management systems (Chartier, 2014). Nevertheless, though the measures for the disposal of BMW are available in India, it is required to take action to enhance the existing management system because of commitment and funding to the removal of BMW safely (Datta *et al.,* 2018). In 2000, 2003, and 2011 the rules of BMW of 1998 were altered. The 2011 draft of BMW was not formulated because of the need for standards and consensus on the categories. The BMW rules were amended in March 2016 by the Ministry of Climate, environment, and Forest Change (Raghuvanshi & Raghuvanshi, 2022). Improper BMWM leads to a considerable risk of nosocomial infection are patients. It also leads to variations in the spread of antibiotic resistance and microbial ecology. Healthcare workers (HCWs) face various difficulties due to the enhanced production of contagious waste, insufficient resources to manage enhanced waste, and intervention strategies used for recycling. Healthcare activities played a vital role in the management of BMW, and the patients were cared forby HCWs every day (Alomri *et al.,* 2023; Sarkar *et al.,* 2024). Notably, current biomedical waste management (BMWM) practices are limited to automated and efficient methods for tracking and sorting waste. Consequently, the need for the use of Artificial Intelligence (AI), Machine Learning (ML), and the Internet of Things (IoT) is significant to enhance the accuracy and efficiency of BMWM. Past studies lacked extensive exploration of the use of effective ML algorithms in the classification and management of BMW leading to potential environmental and health hazards.

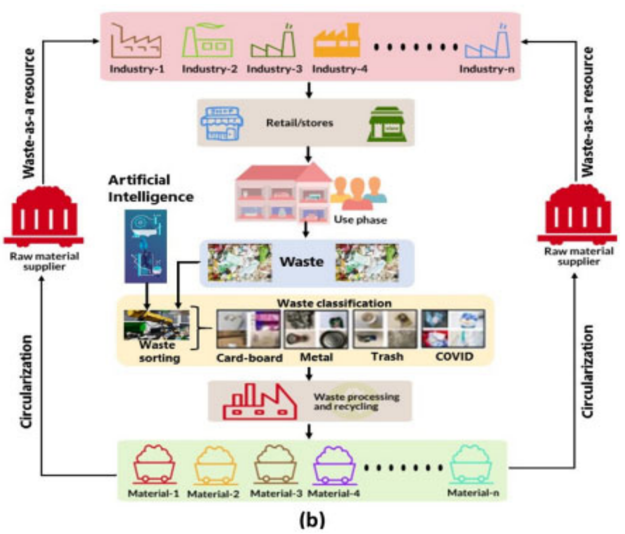
- The current research proposed the Support Vector Machine (SVM) and fuzzy logic systems categorizing and segregating BMW with feature selection of RFID and GPS technologies. The IoT-based monitoring system observes indoor, outdoor, and hazardous materials.

METHODOLOGY

Framework for Garbage Classification System

In their work, Rossi *et al.* (2023) provided recommendations for cycle manufacturing focusing on the cyclical generation of waste with inadequate sorting and recycling. They presented an approach to identifying and categorizing wastage sorting utilizing AI and ML-based classifier Support Vector Machine (SVM)(Rossi *et al.,* 2023). The paper also proposed a similar causality approach in COVID-19 Garbage Classification where course characteristics are important in information processing. These steps involve image development or obtaining the images, feature extraction from these images, and classification. The system adopted is shown in the Figure 1 below:

Figure 1. A). No Proper classification and sorting of



B). Waste classification and Sorting

The researchers in this study opted for an SVM classifier to ensure the integration of various features into the Garbage Classification system, including metal, plastic, paper, and medical and industrial waste. The approach of a deep learning algorithm is used to enhance garbage identification and recognition accuracy using fusion techniques. This process is shown in Figure 2 below:

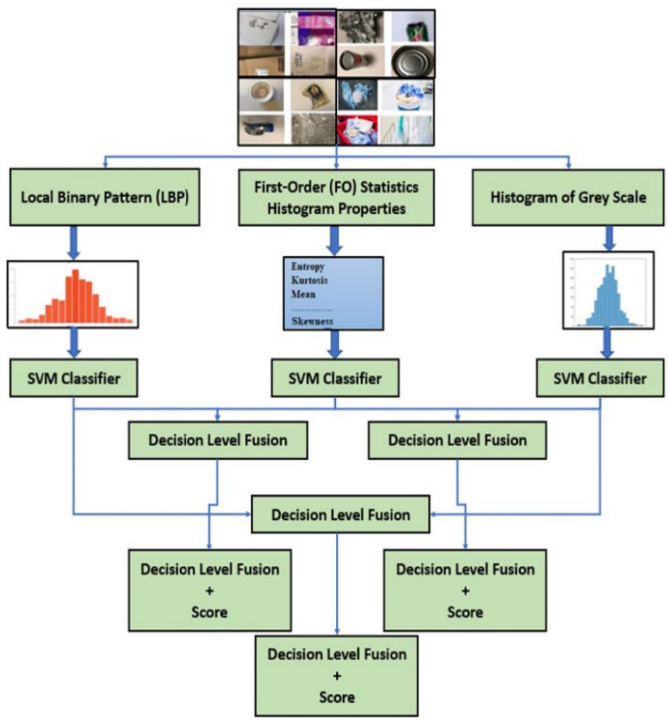


Figure 2. Utilization of SVM Classifier of Various Features of Decision Level Fusion

Categorization and Merging

Image classification and categorization challenges depend upon object appearance or composition by ML classifiers like k-NN, SVM, or ANN. Therefore, the current research opted for an SVM classifier suitable for a large multidimensional functional area. Mohammed *et al.* (2020) resulted in a single predictor to classify the COVID-19 debris using various image structure-based attributes, especially by SVM, which revealed high accuracy characteristics from the concept. Cumulative rating numbers with each activity method are summed according to the rule to use a cumulative score as a presumption when making final ranking determinations (Mohammed *et al.,* 2020). The current study used the mentioned principles to combine multiple combinations for the same three vectors (F1, F2, F3) at the scoring point and evaluate the confidence ratios for each combination. SVM classification of each feature location was carried out separately, but the indicated value of each feature is presented later. The full total mark refers to the final score, which is converted to a level of confidence according to the standards provided. The methods are now in place to handle biological waste daily as BMW's Management could be more effective and efficient with this current technique. By using a fuzzy-based system to classify garbage and an IoT server to track it, the novel proposed method tries to solve this problem.

The study used a fuzzy logic system to classify garbage based on the bag color codes shown. Subsequently, it categorizes using the following criteria:

- P1 (Cost Generator): Something that can be recycled to reimburse costs.
- P2 (Health Hazard): Wastes are hazardous to human health.
- P3 (Biodegradable/non-biodegradable): Is the litter biodegradable?
- P4 (Environmental Impact): Harmful to the environment in any way, the category-based decision-making fuzzy system's hidden layer (HL) selects the best course of action.

The fuzzy-based classification was completed after collecting all packets. Then, IoT performs an essential function after choosing the proper decision process (Figure 3).

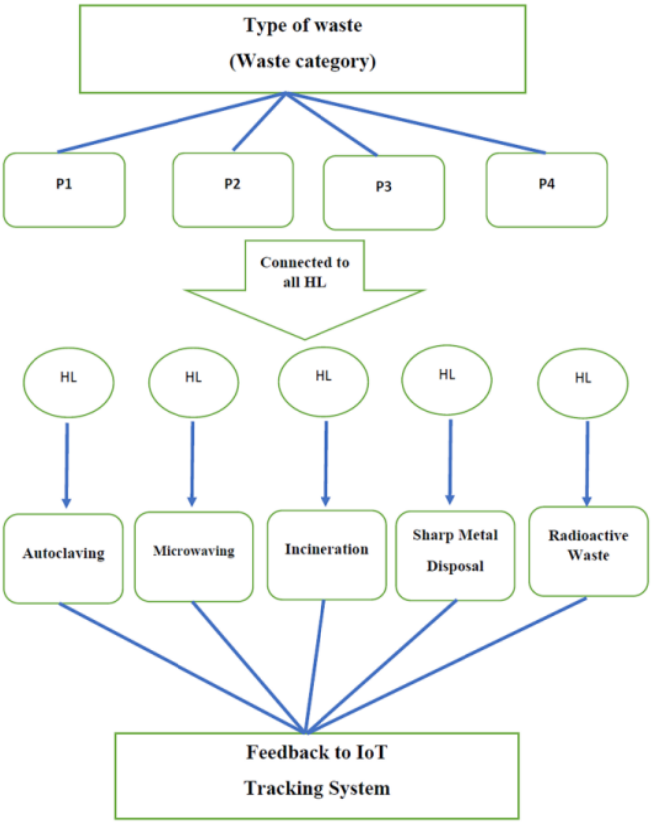


Figure 3. Fuzzy-Based Categorization

IoT-based surveillance and efficient implementation through regulatory policing

An IoT-based fuzzy logic system monitors indoor, outdoor, and hazardous materials. The system uses RFID technology to track indoor waste in waste containers, automatically detecting, storing, and retrieving sensitive data over electromagnetic waves and wireless communication lines. The system is affordable, easily accessible, and color-coded to coordinate with BMW's color-separated trash receptacles and containers (Abdullah *et al.,* 2019). Healthcare facilities use RFID to track waste movement, handling, and temperature and humidity levels. It comprises the RFID tags, detectors, transponders, hardware, and programming. Its flexible attributes make it easy to monitor waste generation, transportation, temperature, and humidity in realtime. The lower RFID tag price is likely due to technological advancement and increasing usage experience design (Babakhouya *et al.,* 2023; Hannan *et al.,* 2015). Both public sector governments of India and civilian corporates have adopted RFID technology in healthcare facilities (HCFs) to tackle waste disposal issues. Again, the errors associated with the disposal of radioactive wastes havea big potential to harm the environment, the personnel, and even patients within the proximity of HCFs (Biswas *et al.,* 2023). Further, Das *et al.* (2020) stated it is imperative to monitor the exterior environment with applications like the GPS to track the position of hazardous material, charts, and analysis (Ganeshan *et al.,* 2017). Thus, this research considered that clinics and similar HCFs can safely and reliably operate the BMWM system while assuring the clients' safety. RFIDs and GPS should be purchased second-hand or reconditioned to contain HCF operating expenses. The recommended system gives the correct and legal progression for radioactive waste from generation to disposal. It can be used in the operative regulation of tasks, elevation of work through-put, and guarding parallel medical risks to the staff.

Data Collection

Due to the lack of publicly accessible statistical data on disposal materials, the data collection process was carried out manually. The researchers used content from Instagram. Photos from the Instagram material database show unedited information. Recycled garbage is challenging to reuse because it is dirty, damaged, crumbled, etc. The Garbage class, which has approximately 300 photographs, the collection contains about 1000 images of each type of garbage. A total of 2400 photographs were taken. Part of the data collection method was to use white card stock and collect pictures showing waste and recyclables throughout the campus, private residences, and other relatives' homes. The data set is not affected by varying lighting and poses in each photo. Figure 5 describes the photographs of the four categories below. Random image rotations, translation, and other ripping procedures were applied around each image depending on the size of each set. These image changes are chosen to occur in different geometries of recyclable materials.

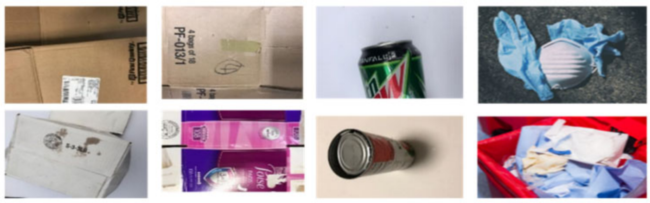


Figure 4. Data collection of the Sample

Data Preparation and Pre-Processing

The data selected for the study consisted of a collection of garbage-related images. Each material photo is 512 x 384 pixels in dimension. To speed up the processing of photographs, they are compressed to 10% of their original sizes. Each input frame's red, green, and blue frequencies are obtained using the Imaging Package's Read JPEG function, which extracts attributes from the images. They provide the information split such that the training dataset contains 75% of the data and the validation database has 25% included using ML algorithms.

RESULTS

The results from the analysis of the recycling process of bio-medical waste in 13/13 respondents showed a need for proper implementation of recycling the waste. In the recycling process, the hand rub and Hand sanitizer were reused to decrease the cost of BMW disposal. Therefore, it is refilled with the liquid before it is returned to be reused. The price and the waste can be decreased by implementing some recycling practices regarding Hospital waste.

AI-Supported Sorting and Classification

The classification and sorting methods were applied in this study, 100 waste images were selected and repeated for investigation. The testing procedures and the evaluation part used 20images. The specificity, sensitivity and accuracy were 91.44 %, 92.39 % and 93.83 %, respectively, when the images were pre-processed. When the photos have not pre-processed, the specificity, sensitivity and accuracy were 86.73 %, 87.98 % and 88.93 %, respectively. The confusion matrix was considered and provided with the summary of the waste classification. The SVM classifier of the confusion matrix was presented. The number of incorrect and correct predictions was given in the count values, where the waste types are broken down at each class in this issue. ANN, SVM and k-NN are the classifiers utilized in these experiments. The findings show that the SVM classifier achieved specificity, sensitivity and accuracy of about 95.9 %, 95.3 % and 96.5 %, respectively.

Decision-Level Fusion System

In the case of the Decision level fusion system, the choices were focused mainly on which participates in each section of the feature. It primarily engages in the selected layout than in the final decision. Possessing a confined item is unnecessary. The final decision is made by focusing on the divisions that receive the highest votes, considered an essential and straightforward criterion. A multi-classification dilemma is managed at this stage (Abd Ghani *et al.,* 2020). In the case of fundamental fusion-level scores, a similar setup is operated for the mixture of three image features, including HoG, FO and LBP, at the decision-making stage. The results showed that the SVM classifier surpassed the majority rule for decision-dependent fusion compared with the k-NN and ANN classifiers. It reached the fusion stage, which is required based on the decision-level fusion in the case of SVM. The various forms of pattern classification were improved significantly based on the majority voting of the fusion. Only two elements were integrated instead of the three features to enhance feature fusion accuracy. Most voting criteria cannot be followed practically because of the usability of two components, considered a multi-classification in classifying the COVID-19 waste classification and challenge under examination. The biggest obstacle is that the two grouping choices must be integrated (Mohammed *et al.,* 2020; Mohammed *et al.,* 2021). The confidence level is measured appropriately by incorporating the groups chosen, and the pattern input of the fusion system concept commences with SVM classification. The fusion system issued the decision of the final Classification. The category level was decided based on the specific set of regulations with three rules controlling the Classification and the location, which is always required by the SVM classification system due to the final classification result by fusion. The feature fusion performance was also executed. The fused level of confidence can be set by relying on the outcome of the class. The classifiers agree upon the results when the two classifiers offer similar class outcomes. The actual intensity of confidence is represented in the fused level of certainty, which is always known as confidence in decisions. In the case of high and low levels of compromise, the setting of the fused level certainty to medium is considered. Integrated confidence is set as a massive level in a condition where one level is medium, and the other previous level is medium. More cautious steps are considered, which is required to view the confidence, which has a shallow level. The integrated levels of certainty are set in the condition where one is medium and another is low. In the fused decisions, the raised conflicts must be resolved when the two classifiers produce different outcomes. Therefore, it is necessary to have advanced confidence levels to have judgment finally in that condition. The decisions that have colossal confidence will succeed in the occurrence of determination of the final class outcome. The prediction that relies upon the strength of the overall class is considered. The low confidence level is also essential in the same way it is done with two classifiers producing a similar outcome.

IoT-Based Tracking System of Biomedical Waste

Every container carrying medical waste is documented, tracked, located, scanned, and labeled from "cradle to grave" using the proposed system. Daily, the healthcare system produces bio-medical waste, which can be reduced using an IoT tracking system. The amount of waste generated is estimated, and the waste is disposed of at a specific period. The system administrator is also assisted by the statistics data analysis module of the system, which is used to dispose of improper or harmful waste disposal.

DISCUSSION

Non-hazardous waste and a general waste of about 85%are generated by medical care industries WHO (2018). Past research conducted by Firouzbakht *et al.* (2017) revealed the percentage of waste generated contaminated waste in hospitals is 38.35%, which provides for 1.31 kg per day per bed, 57.85% of non-infected waste, which consists of 1.99 kilograms per day per bed and 3.75% of chemical and pharmaceutical waste, which is about 0.13 kg per day per bed. Management provides facilities like different colored bins specifically to handle contagious solid waste fitting yellow bags. BMW is handled appropriately using domestic bags or black suit bins to manage solid waste and separate chemical and medical waste compartments. White plastic bags are also used to hold the medicinal waste. Safety boxes are used to control infectious and sharp waste. All these materials are required to operate the BMW properly (Firouzbakht *et al.,* 2017). Additionally, there is no appropriate segregation, recycling, transport, and processing of BMW in developing countries(Khan *et al.,* 2019). Several factors affect the proper management of BMW, among which the environmental problems are most important from the public perspective since managing BMW is an environmentally conscious action (Capoor & Parida, 2021). Other researchers also showed the same results, i.e., when recycling waste materials is implemented, there is a direct reduction in the cost of disposal of the organization's waste. The disposal cost of the waste material is enormous, the hospital incurs more expenditure, and more money is spent when the amount of waste generated is considerable. Past studies also revealed that there are more possibilities in minimizing HCW, safe care, recycling, and disposal initiatives when there is a proper and sufficient reporting system of waste generation and when the waste is appropriately segregated, which directly results in the reduction in the cost of Medicare waste (Lattanzio *et al.,* 2022; Mmereki *et al.,* 2017; Sharma *et* *al.,* 2020). The current study examined that medic are workers can recycle BMW in the organization following proper policy or procedure for recycling BMW. Therefore, adequate management, awareness and training are required for the hospital workers who support implementing such innovative processes as recycling waste (Sharma *et al.,* 2020). Environmental impact, reduced operational cost, government action, incentives, knowledge, facilities, awareness, and high prices are essential to reclaiming BMW. The hospitals require equipment to classify and sort BMW for recycling and should be able to handle the issues caused by medical waste faced by the organization. The recycling process is not only in the control of the management but also depends on third parties. This includes collectors, who must be cautious in handling BMW and safeguard themselves and others, specifically when they hold waste in the low-risk category (Rayan *et al.,* 2021).

In the context of the circular economy, the difficulties in classifying and sorting BMWare examined in this research. The industries utilize the outputs of the recycling processes as the source in the case of classification, sorting, and practices, by which the products of the recycling process are influenced(Baaki *et al.,* 2019; Ozder *et al.,* 2013). In this research, the simulated experiments were conducted to verify the proposed model's performance. ML techniques and decision-level fusion schemes are used in the classification process. The segregation is done in such a way as to achieve a proper separation of waste that comes under the categories to be recycled. It includes plastic, COVID-19 waste, metal, and glass. The results showed that the proposed fusion scheme is superior to the single best-performance feature scheme. The SVM classifier achieved specificity, sensitivity, and accuracy of about 95.9 %, 95.3 %, and 96.5 %, respectively, in the classification process. Anyhow, there is a need to have a better computational resource, and the SVM is comparatively more expensive than the rest of the techniques. The system was considered for classifying and sorting waste at various scales, as suggested by the experiments conducted. This classification system can be deployed only by having a thorough knowledge regarding the present attitude on the segregation of waste and practices of current waste management which varies in different countries. Solutions are optional for the country with a proper approach to waste separation at the collection site.

The classification process should be established in the recycling sites where the source of waste is integrated. This system is installed because of a need for more supply chain recycling centres which are unworthy to be trusted in the case of waste exchanges. A few countries have guidelines on the segregation of destruction, but still, implementation is lacking. Only a small percentage of the domestic sector of southern countries worldwide follows the guidelines of waste segregation (Kaza *et al.,* 2018). Based on the waste collector's advice, dumping is more open in the most inclined spaces as per the instances that lead to integrated waste where the waste can be COVID-19 or other types of garbage (Luhar *et al.,* 2022). Therefore, the current study confirmed that classification and sorting facilities are essential for recyclers. Both developed nations and the countries in the global south benefit from this system in the current waste management practices. Comparatively, the countries in the worldwide south would benefit more than others. By establishing this process, the procedures done in waste management may vary from the present rapid recycling process is enabled.

Conclusion

Waste management came up with some suggestions: the appearance of the bin, removing the bin and replacing it with a poly-ethene bag, and once in a while, the maintenance and the administrative staff for a meeting. Consequently, training programs are necessary for increasing the newcomers' knowledge and actions among the employees. This implies a need for a Diploma Course in waste management; this should particularly be designed for developing countries. Stating that hospital wastes can be recycled, there are also many methods that are not implemented because of inadequate funding and little cooperation from the community. Therefore, the measures considered crucial in waste management include awareness, knowledge, and costs of disposal, as well as incentives. There is causation between the recycling of waste, with economic and financial revenues of the organization, and the environmental impact. However, there remains a requirement, and with the new job chances and scrap, it can be connected with non-harmful waste.

Limitations and Future Implications

The authors acknowledge the present limitation of this study. However, the burden of the developed system's current status is not answerable for the recovery of material and the product received from recycling from the waste resources that are classified and sorted. Further, model development was limited to SVM for fine-tuning and augmentation of BMW. The other limitation is the availability of the data sets. The results can be achieved far better using Convolutional Neural Network (CNN) expanding comprehensive dastasets enhancing the results for real-time BMW tracking in RFID and IoT systems. These advancements will benefit HCWs offering improved public health outcomes through solutions effective in multiple settings.

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