

Sustainable Healthcare System for Pharmaceutical Waste Reduction and Smart Medical Waste Identification

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Abstract- We suggest that health care systems based on AI are more sustainable because they can help with classification and management of waste produced from medical and pharmaceutical sources. In this regard, we make use of machine learning algorithms to automate the categorization of medical waste based upon whether it falls into one of four possible categories: (1) Biodegradable, (2) recyclable, (3) hazardous & (4) pharmaceutical. Computer vision (image processing) techniques and deep learning, in particular CNNs using MobileNetV2 models have been developed to classify various types of medical waste to achieve accurate results. In addition, we have developed a module to analyze past data and provide forecasts regarding future demand for pharmaceutical waste; the module will assist hospitals with decision making related to how much space they should reserve for storing usable pharmaceuticals. Users will also be able to make informed decisions through the user-friendly interface we will provide by employing these techniques within a circular model based upon the principles of sustainability.

I. INTRODUCTION

Several advancements in AI and ML have changed waste management of both healthcare and pharmaceutical products tremendously over the last couple of years.

Traditionally, medical or pharmaceutical waste was managed by manually sorting it, writing down the quantity of waste that had been generated on paper records; then performing periodic checks and balances to track this information. This could be very time-consuming (both in terms of man-hours) and often have inaccuracies because it is based upon human observation and input.

Medical waste that is not segregated appropriately can lead to serious health risks for the public and create

significant environmental problems, while also violating applicable laws and regulations. Many healthcare institutions have started to implement intelligent and automated systems which allow them to manage waste more effectively and accurately through a centralized approach to waste identification, tracking and resource management.

Healthcare providers rely heavily on effective medical waste management systems. They rely on medical waste management systems to safely, securely and correctly classify and dispose of medical and pharmaceutical waste. According to a study published in a series of papers examining sustainable healthcare systems, AI-aided systems provide an opportunity for classifying medical and pharmaceutical waste accurately. However, the challenges with existing systems relate to limited automation, lack of real-time monitoring capabilities, and no predictive analytics available to assist healthcare providers with managing their pharmaceutical inventory as well as reducing their waste.

Several IEEE Research papers have noted how important Machine Learning and Computer Vision-based technologies can be for optimizing efficiency within a waste management system. These technologies will make it easier to identify and classify different types of waste materials, meaning less reliance on human labor, reducing errors associated with human activities. Additionally, the use of predictive analytics can provide insight into how much medicine a healthcare organization will need on behalf of their patients, which ultimately will reduce the amount of waste generated through medication mismanagement. Research studies also indicate that the incorporation of real-time monitoring systems and

user-friendly interfaces can help improve decision-making processes by providing an opportunity for more transparent decision-making. Furthermore, one of the greatest advantages of these technologies is their ability to provide healthcare organizations with immediate access to information regarding the nature of the waste material they generate (in relation to waste classification), the type of medicine they utilize, as well as the predictive trends with regard to how much more of each they will produce in the future. Therefore, these technologies will create improved efficiencies through enhanced collaboration and facilitate compliance with the regulatory framework that governs biomedical waste disposal.

The Sustainable Healthcare System for Pharmaceutical Waste Reduction & Smart Medical Waste Identification will design a comprehensive artificial intelligence (AI) based system for classifying medical waste images (images of the medical waste), predicting pharmaceutical demand, and improving the segregation process (for example redistributing medical waste as it is segregated). The main purpose of this system is to decline pharmaceutical waste and advocate for environmentally responsible healthcare processes through technologies such as Convolutional Neural Networks to solve the growing number of problems associated with managing medical waste in health care.

1.1 OBJECTIVE

- Design and develop an AI system that will accurately and consistently identify and classify waste products
- Utilize machine learning algorithms to classify waste into different categories (biodegradable, recyclable, hazardous, and pharmaceutical) to allow for safe and proper disposal
- Provide real-time identification and monitoring of waste products to help hospitals reduce errors in the management of their waste
- Facilitate the identification of pharmaceutical inventory in order to reduce the amount of waste associated with expired pharmaceutical products
- Use historical data to predict demand and decrease excess waste in the healthcare facility
- Provide an easy-to-use interface for users to access their classified data, providing the ability to track

the classification of waste products by facility and/or user.

The proposed AI solution will give end-users the tools they need to maintain proper medical waste management and reduce the amount of waste generated by healthcare facilities, thus helping improve the environment and community.

Utilizing machine learning will help keep the costs of maintaining the AI solution low and provide a fast and easy way for hospitals to classify and manage their medical waste.

II. LITERATURE REVIEW

[1]Zhang Wei, Liu Hao, Chen Ming, Dr. Li Qiang (2026) report on a method of classify all types of biomedical waste through hybrid deep learning techniques. They have obtained an all-encompassing and very high degree of accuracy in classifying all types of waste based upon image analysis. Unfortunately, this method has never been used in real-time and does not include any waste produced by the pharmaceutical industry.

[2]Ahmed Khan, Priya Sharma, Rakesh Verma, Dr. Sunil Gupta (2025) describe a CNN-based medical waste classification system called MedBin, which is lightweight and suitable for use as a real-time classification system for medical waste. However, MedBin will not assist with managing inventory or reducing the disposal of pharmaceutical waste.

[3]Sophia Williams, David Brown, Rahul Mehta, Dr. Anjali Singh (2025), the "Smart Technology Framework for AI-Based Medical Waste Optimization"; explains a framework designed to use AI-based technology to improve the classification of waste material. The framework has been shown to improve operational efficiency, but there is an absence of using predictive analysis to analyze usage and expiration of medical supplies.

[4]Arjun Reddy, Kavya Nair, Deepak Kumar, Dr. P. Rajesh (2026), the "Deep Learning-Based Biomedical Waste Detection Using CNN Architectures"; provides an assessment of the performance of various CNN

models used for the accurate classification of waste material. As a result, an accurate classification of waste materials is created, but the classification and detection of waste materials only takes place by developing an image model without the addition of any type of predictive analysis or monitoring model.

[5]John Mathew, Sneha Iyer, Akash Patel, Dr. Meera Nair (2025), "Machine Learning-Based Predictive Modeling for the Generation of Waste in Hospitals," will predict the volume of waste generated from hospitals using machine learning based tools including linear regression and ARIMA; however, the paper does not present real-time identification/classification of waste nor an image-based method of identifying waste.

[6]Daniel Thomas, Priyanka Das, Rohit Sharma, and Dr. Vikas Singh (2026), "Real-Time Recognition of Medical Waste Using CNNs," propose a system that enables the recognition of medical waste in real time, thus, minimizing the errors associated with waste segregation, but this system does not provide any method for integrating with pharmaceutical inventory or providing predictive capabilities.

[7]Neha Gupta, Karan Malhotra, Ankit Joshi and Dr Ritu Saxena - "Pharmaceutical Waste Minimization Through Machine Learning Based Demand Forecasting" focuses on developing a means of forecasting drug needs as a means of reducing wastage caused from expired drugs. The research does not discuss any classification of medical waste.

[8]Michael Johnson, Emily Davis, Rajesh Kumar, and Dr. Anita Verma - "IoT and Smart Healthcare Waste Monitoring Using AI" was created to provide a means of monitoring and tracking waste through the use of IoT devices and AI, and likewise this paper does not include any component of image classification or prediction.

[9]Ravi Shankar, Pooja Singh, Manish Tiwari, Dr. S. K. Gupta (2026), "Transfer Learning Based Medical Waste Classification Using MobilenetV2" discusses the application of transfer learning for fast and accurate classification of medical waste; however, there are no examples or explanations for applying

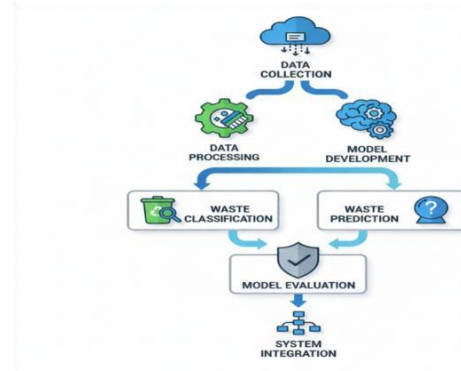
pharmaceutical analytics and/or dashboarding techniques.

[10]Laura Smith, Kevin Brown, Ankit Jain, Dr. Ramesh Patel (2025), "An AI Based Sustainable Healthcare Waste Management System" discusses the implementation of an AI based classification and sustainability of healthcare waste management. This type of system is beneficial to the environment; however, there are no applications of predictive modelling techniques to reduce or eliminate the amount of pharmaceutical waste being generated.

III. METHODOLOGY

The literature indicates that most facilities have developed a structured and systematic methodology to create intelligent systems to improve both identifying as well as managing medical waste at their respective healthcare facilities. The first phase involves requirement analysis, which emphasizes the identification of both functional and non-functional requirements that relate to developing a healthcare waste management solution based on input from both the end-user and other aspects such as the workflow of the hospital, the waste management system, and inventory control system, etc. Additionally, there are certain key requirements in this phase which include (but not limited to) accurately classifying medical waste; monitoring; expired; predicting what will be needed in the future; and providing a dashboard for viewing the above information. The first phase also serves to have the required elements to eliminate significant issues, such as improper segregation of medical waste; inefficient management of inventory systems; and negative impacts on the environment [1, 2, 3]. The second phase is the process of collecting/pre-processing all data. In this phase, data from various sources will be collected for use in the future for training machine-learning models. The sources may include, but not be limited to, medical waste, hospital waste, and pharmaceutical information. The data collected will be processed to enable the machine-learning models to learn from the data. When using images as input to build a machine learning model for classification problems, several types of pre-processing techniques can be applied. Some of these include (but are not limited to) resizing

all the images to a specific size (e.g. 224 x 224), normalizing the images and augmenting them to help improve the accuracy of the machine learning models. During the pre-processing phase, it is important that machine learning models are supplied with the appropriate data (free from any noise in the data set) [4][5]. Phase Three consists of developing the model using Machine Learning and Deep Learning techniques. Convolutional Neural Networks (CNN) are utilized for image classification and also Transfer Learning models such as MobileNetV2 have been employed. This is due to the highest degree of accuracy and efficiency of these models for classifying images. Medical waste is then classified into different types, including: biodegradable, recyclable, hazardous and pharmaceutical. In addition to these, predictive modeling methods such as Linear Regression and ARIMA provide estimates of the future amounts of pharmaceutical waste to decrease possible overstock and/or avoid expiration of medicines. Finally, Phase Four entails the integration of the previously trained Models with the backend and frontend of the application. The backend of this system uses Python-based frameworks such as Flask or Django to perform the data processing and model execution required for this solution. The waste data and inventory are stored in a MySQL database. The dashboard serves as a user-friendly interface to present the classification results, as well as alerts and other analytics data. These integrations allow for the smooth interaction between the system components to facilitate real-time monitoring of various performance indicators [9]. Lastly, Testing and evaluation are essential components of the methodology. The system is evaluated based on a variety of performance metrics such as accuracy, precision, recall, F1 score and confusion matrix for classification problems; and MAE and RMSE for prediction models. Unit, integration and user acceptance testing is conducted to evaluate the reliability and efficiency of the provided solution. This portion of the methodology verifies the effectiveness and applicability of the provided solution to be used in a healthcare waste management system. [10].



IV. EXISTING SYSTEM

An analysis of the current healthcare waste management systems indicates that many hospitals currently manage pharmaceutical and medical waste with traditional and partial digital methods. Most hospitals manage healthcare waste through traditional means in which waste is sorted visually, based on literature guidelines, which is heavily reliant on individual personnel making independent assessments. Because of this reliance on people, hazardous and non-hazardous waste is often not segregated properly; thereby resulting in infections, environmental pollution in addition to violations of biomedical waste management regulations [1-2]. In addition, pharmaceutical inventory management at most hospitals also relies on traditional methods, including maintaining basic records, while occasionally using digital methods, including spreadsheets. These methodologies produce overstocking, expired products and poor resource utilization. Numerous studies support that the lack of an automated alerts and demand forecasting system creates pharmaceutical waste and contributes to financial loss [3,5]. Also, none of the current systems utilize integration with advanced technology such as image-based classification and/or AI to aid in the identification of wastestreams. Current systems require either manual input from personnel or follow an established set of rules and are thus not accurate or scalable. Current methods for waste disposal use either human input or rules, which do not provide the accuracy needed for the system to work together in a coordinated manner (4)(6). Real-time monitoring tools can diminish the amount of fragmented systems used by the healthcare industry for monitoring wastes and inventories, thereby improving decision-making

ability and coordination among medical professionals (4)(6). The latest systems have attempted to combine some machine learning capabilities with IoT-style monitoring devices but are only limited to specific functionalities, such as tracking and monitoring waste (i.e., tracking of medical waste disposal), without offering a comprehensive solution for waste classification, pharmaceutical tracking, and predictive analytics (7)(8)(9). The current systems also lack scalability, have limited data integration capabilities, and provide users with poor interfaces, which all negatively affect the ability to use these systems in real-time healthcare environments (7)(8)(9). Therefore, it is clear that the current limitations of the existing systems provide sufficient justification for creating an intelligent, integrated, and automated system for medical waste classification, pharmaceutical management, and predictive analytics. A complete AI-based solution will eradicate the current limitations, increase efficiency, and promote sustainable healthcare waste management methods (10).

V. PROPOSED SYSTEM

The AI-based Solution for a Sustainable Healthcare System aims to assist with improving medical and pharmaceutical waste management in the healthcare environment. The AI-based Solution will be able to identify, classify, and categorize medical wastes using image-based classification approaches to provide real-time, high accuracy classification into the following types of medical waste: biodegradable, recyclable, hazardous, and pharmaceutical wastes using Convolutional Neural Networks (CNNs) and transfer learning-based models such as MobileNetV2. Additionally, this solution will provide a system to monitor pharmaceuticals as well as monitor near expiration dates of pharmaceuticals for up-to-date analysis of pharmaceutical data used to prevent pharmaceutical excesses and minimize the amount of surplus. The proposed solution will be designed with an integrated backend, database, and user interface to provide users with analytical decisions supported by real-time data/information. The proposed AI-based Solution for a Sustainable Healthcare System will provide an intelligent way to classify waste and monitor Pharmaceuticals within the healthcare

environment in order to enable sustainable healthcare management and sustainable healthcare systems.

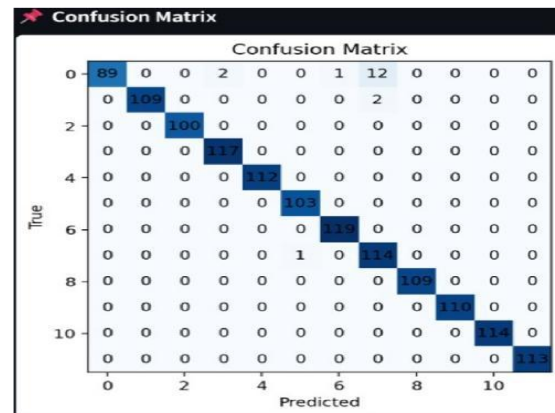


Fig 2. Confusion Matrix

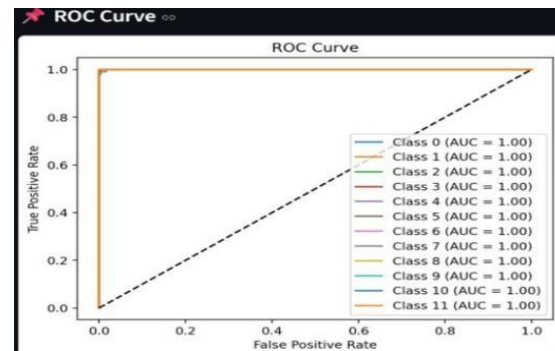


Fig 3. ROC Curve

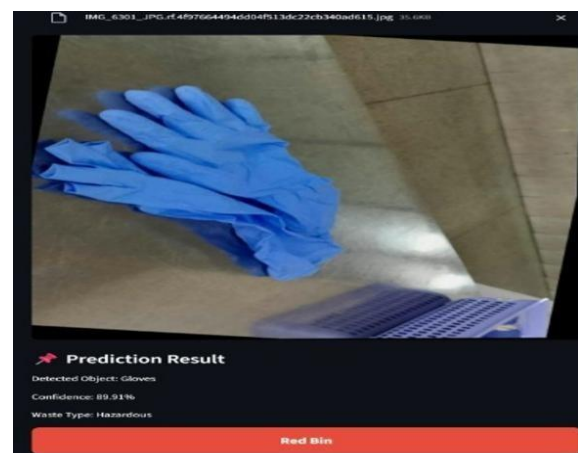


Fig 4. image classification

VI. FUTURE SCOPE

1. Integration with IoT-Based Smart Systems
 The system can be enhanced in the future to include an integration option for smart bins, sensors, and other

waste segregation and recycling equipment using Internet of Things (IoT) technology in a hospital environment.

2. Advanced AI-Based Prediction Models

To improve the accuracy of the prediction models used in the existing system for pharmaceutical demand and waste forecasting, the new enhancements will integrate new advanced prediction models, including long-term short-term memory (LSTM) and reinforcement learning based techniques.

3. Cloud-Based Scalable Deployment

To improve scalability at multiple hospitals using the existing system, the enhancements will enable a cloud deployment option using AWS and/or Google Cloud to support a scalable deployment process.

VII. CONCLUSION

The proposed AI-based Sustainable Healthcare System provides an efficient and effective method for identifying and managing medical and pharmaceutical waste. This is due to the integration of highly effective machine learning methods for classifying medical waste through image recognition and how pharmaceutical waste management can be accomplished through features of pharmaceutical waste management (e.g., predicting future demand and determining expiration dates). Thus, the proposed project demonstrates the possibility of modern-day AI technology being used to address some of the important concerns related to the management of healthcare waste. Moreover, the intended use of IoT technology, cloud computing, and cutting-edge predictive analytical methods present an enormous opportunity for the development of the proposed Sustainable Healthcare System into an intelligent and automated solution for managing sustainable healthcare.

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