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A NOVEL WASTE MANAGEMENT MODEL USING IOT IN SMART CITIES

Abhik Patra[1], Hritam Basu[2], Prantik Roy[3], Ranajit Saha[4]

[1,2,3,4]School of Computer Science Engineering, KIIT University, Bhubaneshwar, India

[1]abhik2005personal@gmail.com , [2] hritambasu1@gmail.com, [3]prantikroy008@gmail.com, [4]rcsaha1803@gmail.com

***Abstract*—**The rapid increase in urbanization, industrialization and population growth has caused an unprecedented surge in waste generation. Traditional waste management systems which depended on fixed collection schedules and inefficient routing are struggling to cope with escalating volume and complexity of waste. The existing waste is also harmful for our health and environment. Accumulated waste serves as an ideal breeding ground for bacteria, insects and flies increasing the risk of food borne illness. Decomposing waste also releases toxic gases such as Carbon Dioxide, Methane and Nitrous Oxide contributing to air pollution and aforementioned illnesses. Hazardous waste like electronic items and plastic, disrupts ecosystems, improper segregation of waste at household and industrial level remains a major challenge, adding significant pressure on already over burdened landfills. This article proposes a multifaceted approach which requires Internet of Things powered self–sustainable smart bins each being monitored via web–interfaces which are accessible to the general public to increase transparency & accountability. We are also promoting proper disposal of domestic waste by adopting a reward based approach using block-chain. While also focusing on sustainable recycling methods such as material flow mapping and other technological assessment.

***Index Terms* —** Smart Bins, Waste Segregation, Environmental Monitoring, Waste Segregation, Sustainable Recycling

1. Introduction

The rapid growth in urbanization and industrialization has matched with accelerating population growth.This had led to the increase in generation of municipal solid waste(MSW) world wide [1].According to United Nations, nearly 66% of the global population is projected to live in the life style at urban areas by 2050,this will also cause intensifying the demand on already overburden waste management system.The traditional waste collection and disposal mechanism was used by missing the statistic schedule inefficient routes and the data needed reach up to be integrated.These are proving to be inadequate in addressing the huge volume and the difficulties in urban waste [6].

This lack of infrastructure contributes to increasing operational cost,which wastes the resources but also possess severe threats to public health,environmental sustainability and urban livability [7].When the uncollected or poorly managed waste remains this leads to the hostage for health issues which includes the spread of vector-borne diseases such as malaria, dengue and food borne illnesses like typhoid, gastroenteritis and cholera [9].

Overflowing bins and illegal dumping sites hosts the breeding ground for retardants ,flies and mosquitoes which creates serious sanitation issues in addition to health risks ,decomposing waste creates harmful greenhouse gases like car- bon dioxide ,methane, sulphur-dioxide,worsening the climate change and air pollution.The improper duping of electronic , plastic ,and hazardous materials into dump-yard or the Nearly water-bodies endangers the ecosystem and aquatic life .This multidimensional challenges proves the urgent requirement for a more intelligent, responsive and sustainable approach towards the waste management [7].The recent discoveries in the field of technology offers a promising method to address these problems. IOT, AI and cloud computing have risen as a powerful enabler of real time monitoring ,predictive analysis and automation. In this context ,Smart waste management (SWM) systems showing promise towards IOT based sensors and data driven decision taking tools proving a revolutionary solution [2].

By integrating the smart Bins,GPS enabled and centralized monitoring platforms, SWM system enables dynamic scheduling, efficient routing and proven segregation practices [6].This system finally used to optimize operational performance and also contribute to the environmental conservation and public awareness [10]. This research aims to explore and evaluate the application of an IOT based smart waste management framework which is capable of surpassing the limitation of traditional conventional methods. This study will examine how real time data acquisition, predictive algorithms and intelligent infrastructure can be harmonized to create to sustainable cost effective and scalable waste management system aligned with smart city objective ,by addressing the critical flaws in the existing system, this research aspires to contribute the development of cleaner, healthier and more effective urban environment. The rapid increase in urbanization, industrialization, and population growth has caused an unprecedented surge in municipal solid waste generation [1]. Traditional waste management systems, which depend on fixed collection schedules and inefficient routing, are struggling to cope with the escalating volume and complexity of waste [8]. The existing and unscientific methods often result in delayed waste collections, overflowing bins, higher operational costs, and environmental concerns such as increased carbon emissions and pollution [5]. Additionally, the rising consumption of packaged goods, plastics, metals, and textiles adds to the complexity of segregation, disposal, and recycling processes [8].

Waste is a crucial issue nowadays which is also harmful for our health and environment.Accumulated waste serves as an ideal breeding ground for bacteria, insects, and flies. These flies often come into contact with food and can transmit harmful pathogens by laying eggs, increasing the risk of food borne illnesses such as food poisoning, typhoid, gastroenteritis, and salmonella infections. Insects and mosquitoes thriving in waste also contribute to the spread of vector-borne diseases like malaria and dengue [3]. Additionally, rodents and stray animals that feed on unmanaged garbage further spread infections and pose significant health threats [11]. Improper waste disposal not only impacts health but also severely affects the environment. Decomposing waste releases toxic gases such as carbon dioxide, methane, and nitrous oxide, which contribute to air pollution and exacerbate respiratory problems [6]. Furthermore, hazardous waste like electronic items and plastics, when dumped in water bodies, harms aquatic life and disrupts ecosystems, indirectly endangering human health [8].Also many cities continue to rely on static, time-based waste collection systems instead of adopting real-time, data- driven approaches, leading to issues like overflowing bins, missed pickups, and unnecessary fuel consumption due to inefficient routing [4]. At the same time, improper segregation of waste at the household and industrial level remains a major challenge, as mixed waste complicates recycling and adds significant pressure on already overburdened landfills [2]. Re- cycling infrastructure in many regions is still underdeveloped, resulting in the majority of waste being dumped in landfills or incinerated rather than being processed for reuse [11].

In addition, the use of outdated technologies and inefficient processes contributes to high operational costs for waste collection, transportation, and treatment [10]. Poor waste man- agement also causes severe environmental and health hazards, including air, water, and soil pollution, and provides breeding grounds for pests and diseases [11]. To make matters worse, there is a lack of public awareness and responsibility towards proper waste disposal, combined with resistance to adopting new waste management systems, which further aggravates the problem [7].

2. Literature Review

In [1] Developing a model that attains a high accuracy in discriminating waste into biodegradable and non biodegradable classification while also working well with hardware dustbins in real time. Using ResNet50 (Deep Learning Model) implemented in a micro control unit in dustbins along with sensors to detect if dustbin is full or not, motion sensor to take an image of the waste for classification and using a servo rotator to act as a segregator of waste to put biodegradable waste in one compartment and non biodegradable waste in an- other compartment. ResNet50 had an accuracy of 95.6% which is greater than pretrained models of VGG16 and AlexNet yielding an accuracy of 83.68% and 71.44% respectively on a data set of 5112 images from Kaggle and Open source.

In [2] Classifying biodegradable and non biodegradable waste using a pre-trained VGG16 model since it provides hierarchical features from images. Data is firstly taken in the form of images which is then preprocessed into Training (80%) and Testing (20%) from which the data is again passed into the 16 convolutional layers of VGG16 and then the output is provided classified into a gradient from Biodegradable waste to Non Biodegradable Waste, the gradient having 8 types of classification. The CNN based model categorizes waste into organic and recyclable types with a notable accuracy of 94.9%. The VGG16 model when trained on WaRP data set along with Mobile-Net-v2 yielded a classification accuracy of 75.6%.

In [3] The aim of paper is to develop efficient method for treatment and management of liquid waste with an emphasis on sustainability and environment protection. Here various method treatment technologies such as sedimentation,filtration,chemical treatment, biological process is used to implement in real life study. It is found that selection and integration of technology depend on waste type,volume and infrastructure.The combination of physical and biological treatment yields for effectiveness which can be achieved by adequate planning, efficient management.

In [4] Develop a smart compost system using WSN and LoRa for real-time monitoring. Prototyping with Arduino, sensors, Raspberry Pi, LoRa; data monitored via Telegram for 10 days. 100% functional success, real-time compost monitoring achieved; minor packet loss noted.

In [5] Determine the best WTE technology for Manila using MCDA and AHP. Used AHP with environmental, economic, technical, and sociocultural criteria to compare anaerobic digestion, incineration, and pyrolysis. Environmental priority; anaerobic digestion chosen, producing large amount biogas in 21 days.

In [6] The aim of the paper is to develop a smart waste monitoring system that can provide real time status of a dust bin. Here the proposed model uses Arduino Uno as a controller with ultrasonic and gas sensor to monitor dustbin fill level and data is transmitted by GSM/GPTS module. Real Time data from sensor is uploaded to the website and proposed system sends message alert to authority when dustbin will be filled and also prototype was tested confirming reliable and expected performance.

In [7] Developing Smart Solid Waste Management System using Block chain and IoT for Smart Cities. Research conducted by GreenRedeem showed that a reward based approach works 2 times better than a punishment focused approach. Using that we can accept input from IoT powered dustbins containing name,address and weight of waste which can then be processed through Block chain networks to distribute rewards more transparently. For smooth solid waste management, it also suggests GPS based tracking, smartphone navigation and routing among different departments. Proposed System was deployed on Ethereum Virtual Machines using block chain testing networks such as Matic, BSC and Ropsten among which Matic was the most efficient yielding 5.18 s for Transaction Time, 23s for 10 block confirmations, 2.37*10^-5 USD as Gas fee and 3.3 s for sending ETH to the user.

In [8] To tackle the growing e-waste crisis in China caused by rapid electronic consumption and illegal imports.The paper aims to analyze material flow, recycling technologies, and newly introduced policies. The study reviews China's current e-waste generation, collection systems, and recycling technologies .It examines government regulations like China RoHS and recovery policies for household electronics.A policy and technical analysis was conducted to assess the impact and challenges of implementation. China has introduced key e- waste management policies promoting Eco-design and recycling regulation.These efforts have improved awareness and begun to reduce environmental harm from informal recycling.However, gaps remain in enforcement, data tracking, and regional consistency in policy execution.

In [9] The aim to develop an IOT based smart bin system to reduce food waste, reduce carbon emission, increase individual accountability for waste. Here the method like web based dashboard and RFID based student monitoring system is used for user interaction ,insights,alerts and smart bin system is developed with weight,gas,infrared sensors integrated into micro controller based design. The implementation of smart bin system provides real time monitoring of food waste, carbon emission leading to optimized waste collection.

In [10] To develop environmental management pertaining to heavy industries producing a lot of waste which gets dumped without being treated. Here we can use an innovative idea towards waste management for people like buying trash bags which cost according to the size of bags which accordingly hence promoting sustainable waste management and promoting Reuse-Reduce-Recycling to reduce amount of waste being generated domestically.

In [11] To develop a web based system which is centralized to improve chemical inventory management, enhance safety, and reduce hazardous waste in university laboratories. The use of ChemSorter which is created in the University of Balamand. It is used to bring together the four main modules which are inventory, experiment tracking, safety data, and reporting. This is to manage chemical use and waste digitally. The System used is improved the management by real time tracking of the chemicals .It monitors the user using the chemicals .It practices by minimizing chemical waste by reuse and accurate inventory management, reducing environmental risks by proper disposal procedures, and promoting a culture of responsible chemical handling that supports long-term ecological and safety goals.

3. Proposed Model

To address the growing challenges of waste collection and management, an IoT-based Smart Waste Management (SWM) system is proposed. This system utilizes smart garbage bins (SGBs) equipped with sensors to monitor the fill level, temperature, and overall condition of the bins in real-time. The collected data is transmitted to a centralized platform via wireless communication protocols, where it is analyzed using AI-driven algorithms. Based on this analysis, the system can predict when a bin will be full and automatically schedule pickups, reducing overflow issues and missed collections.Additionally, the proposed system integrates GPS-enabled waste collection vehicles and route optimization algorithms to minimize travel time and fuel consumption, lowering operational costs and greenhouse gas emissions. By enabling real-time monitoring and predictive analytics, the system ensures timely waste collection, efficient resource utilization, and environmental sustainability.

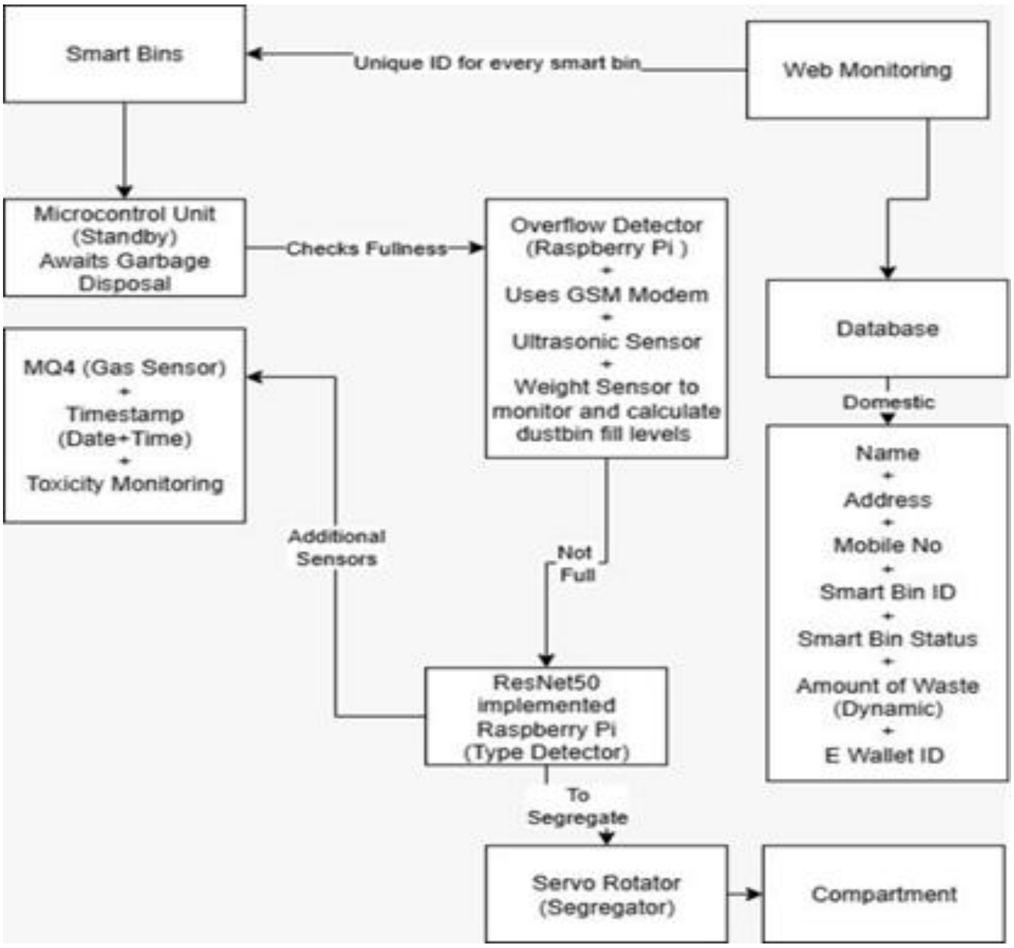

Fig. 1. Working Model of Smart Waste Management

Beyond operational efficiency, the solution supports advanced features such as automated waste classification, dig- ital notifications for citizens, and incentive-based recycling programs. Cloud-based dashboards provide decision support for municipal authorities and dispatchers, while mobile applications keep citizens informed about pickup schedules and encourage responsible disposal practices. Overall, this IoT- driven solution transforms waste management from a static, schedule-based approach into a dynamic, data-driven system that improves efficiency, reduces environmental impact, and aligns with the smart city vision.

From Figure 1, emphasizing on the multifaceted approach, for the ground level of domestic waste, we propose the implementation of IoT Powered Smart Bins having two compartments, with a Tracking ID for each bin, tracked via web monitoring applications. These Smart Bins are to be equipped with MQ4 Gas Sensors, ResNet50 model implemented Rasp- berry Pi Boards, Weight Sensors, Webcams, Servo Rotators, GSM Modems and Ultrasonic Sensors. A micro-controlled unit awaits waste disposal. When waste is deposited, an overflow detector is alerted, a system based on Raspberry Pi Uno Board which checks the amount of fullness of that particular garbage bin with respect to the weight of waste. If the amount of waste deposited is greater than the amount of waste that can be stored by the smart bin at that particular point of time then the waste is to be rejected and an message stating that the smart bin is full is to be sent to the user to whom the unique ID of the smart bin is attributed to according to the database. When the smart bin is not full, then the image of the waste is taken by a motion sensing webcam to determine whether it is biodegradable or not. This helps ensure proper segregation of waste deposited. To check for the type of waste, the image taken is then processed and checked via a second Raspberry Pi Board with ResNet50 model implemented alongside implementing YOLO algorithm to correctly and efficiently determine the type of waste that has been deposited.ResNet50 has been implemented as it is a model that attains a high accuracy in discriminating waste into biodegradable and non biodegradable waste classification and since it also works well with hardware dustbins in real time using DenseNet and ImageNet for image classification. Based on the type, then the waste is disposed into the correct compartment by the servo rotator also known as the segregator in this case. Each compartment of the smart bin also has MQ4 Gas Sensors to monitor toxicity levels within the bin, while also having a Timestamp attached to the data which is publicly available to the user and the garbage collectors. This improves accountability and transparency among general public. Along- side the implementation of smart bins, it is also important to focus on promoting proper disposal of waste. This can be done by adopting a reward based approach over a punishment based approach. According to a study done by GreenRedeem, it has been found that a reward focused approach yields twice as better results as compared to a punishment based approach. We propose distributing rewards via public block chain which will be strengthened by smart contracts where solidity can be run on Ethereum Virtual Machines (EVMs). Let us take Ethereum as a mode of transaction between waste management authorities and general public. A crucial aspect of waste management is also tied to waste recycling methods, the most prominent being Minimal Flow Mapping Approach which tries to reduce waste generation by tracing the life cycle of waste from generation which leads to easier collection, disassembly and in the end recycling.

4. Result Analysis

From the above flow diagram Fig 1, the system wants to demonstrate an integrated IoT smart waste management framework in the smart cities. The diagram combines the sensor based detection AI driven classification, Block-chains, Smart contract ,Web-monitoring ,Citizen engagement ,etc. these are the core components of the ore diagram. The collected waste data is transferred to a web-monitoring platform where citizen inputs and complaint logs are already integrated to enhance real-time monitoring. This directly increases citizen participation and accountability which led to improving overall collection rates . The over-flow count is reduced through continuous monitoring and automated SMS alert trigger. Response time is optimized by using IoT GSM/GPS tracing module and smart routing algorithms. Citizen participation is increased through Block-Chain backed incentive and transparent continuous reward distribution. Token distribution is fair and verifiable due to immutable Block-chain records leading to long term community engagement.Overall this model represents a scalable, data-driven, and community-inclusive approach to urban waste management, aligning with circular economy principles and sustainable smart city objectives.

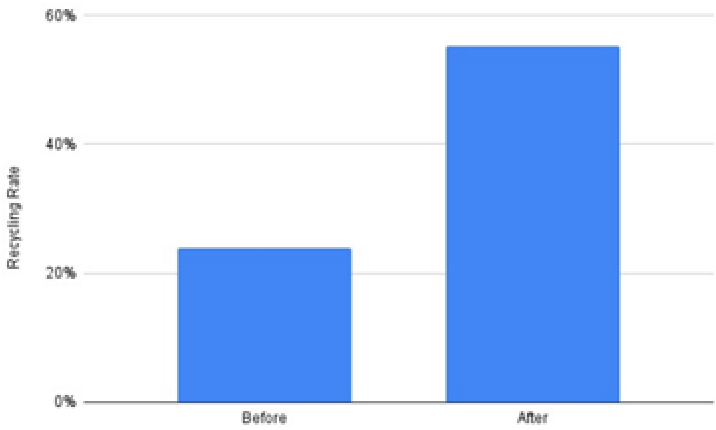

Fig. 2. Predicted Recycling Rate before and after implementation

Figure 2 shows that before the implementation of the model, the recycling rate which was around 24 % which has increased to 55.18 %. This shows that amount of waste being recycled has increased more than twice hence showing the effectiveness of the model.

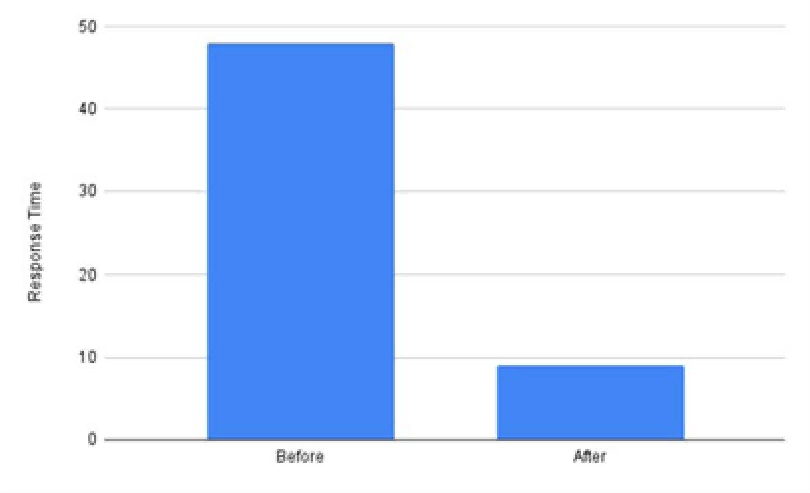

Fig. 3. Predicted Response Time before and after implementation

Figure 3 shows that before the implementation of the model, the response time which was 48 hrs has declined to 9.08 hrs. This in turn shows that response time has been reduced thereby showing that the model is effective in addressing issues quickly and effeciently.

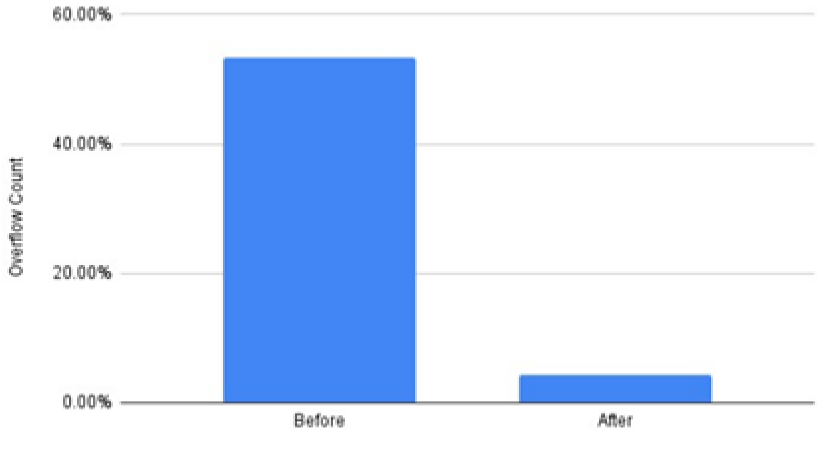

Fig. 4. Predicted Overflow Count before and after implementation

Figure 4 shows that before the implementation of the model the overflow count which was around 53.33 % has declined to 4.25 % . Considering the main focus of the model was to manage overflowing bins, this output shows a positive approach.

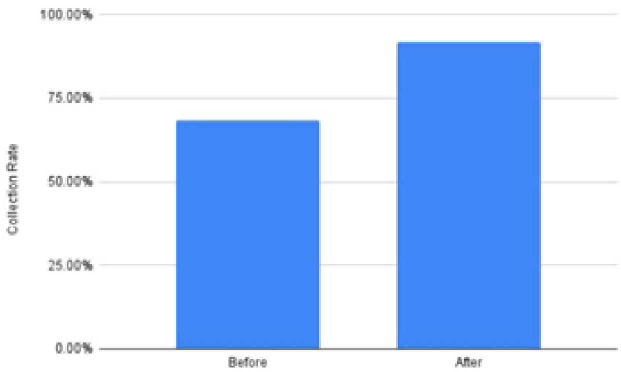

Fig. 5. Predicted Collection Rate before and after implementation

Figure 5 shows that before the implementation of the module the collection rate was 68.23% which has increased to 91.62%, which shows the improvement in the efficiency of the system.

5. CONCLUSION

In the above graphs it has been shown that a consistent trend in efficiency matrices like (collection, recycling, participation) and downward trend in negative matrices (Overflow count, response time) post smart waste management operation. The introduction of token reward system created a positive feedback loop that accelerated behavioral change in cities.

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