AI-DRIVEN SMART BINS

King Abdul Aziz University
Faculty of Computing and Information Technology
Computer Science Department

by:

Nesreen Alsulami -
Rama Najjar -
Raseel Alghamdi -
Maali Alghafari -

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1 Introduction

The environment is one of the most important factors affecting the quality of life and human health, as it plays a vital role in providing the natural resources necessary for survival and growth. In light of the increasing environmental challenges, it is our duty to propose and develop solutions to protect and preserve the environment. Preserving the environment is not just a moral obligation; it is also the foundation for achieving sustainable development, which is one of the objectives of Saudi Arabia's Vision 2030, through promoting the use of renewable energy, developing smart cities, and improving waste management.

2 Problem Definition

The waste problem in Saudi Arabia is a significant environmental issue due to rapid population growth and increased consumption. The rapid population growth resulted in a substantial increase in household and industrial waste, creating significant challenges in collection and processing, and negatively impacting the urban landscape in KSA. In addition, the recycling rate in Saudi Arabia remains low compared to other nations, as much of the waste is not sorted or treated effectively for reuse.

3 Suggested Solution

The optimal solution is to create smart waste containers in Saudi Arabia using artificial intelligence to enhance the waste management process. The containers will have sensors to monitor their fill level. When they are nearly full, these sensors will automatically notify the specialized center for waste collection and container emptying. Furthermore, the containers will feature an intelligent sorting system that utilizes AI technologies to categorize waste into various types, such as plastic, paper, and metal. This enhances the recycling process's efficiency and minimizes the requirement for manual sorting.

The system will help reduce pollution, improve waste collection response, and lower costs by minimizing unnecessary collection rounds. It will also promote environmental awareness and support sustainability efforts.

4 Highlight the Novelty or Uniqueness

1. Using advanced AI algorithms to sort waste

   The project utilizes advanced AI algorithms like deep learning and machine learning to accurately and efficiently sort and classify waste, reducing human errors and enhancing recycling efficiency.

2. Collect real-time data to enhance operational decisions

   The project uses advanced sensors to collect real-time data, such as fill levels, which helps improve operational efficiency by reducing unnecessary truck trips.

3. Integrating advanced sensor technologies to increase the accuracy of waste classification

   The project integrates a variety of sensors, such as high-resolution cameras, optical sensors, and weight sensors, which helps improve the recycling process.

4. Improving sustainability

   The project emphasizes sustainability by enhancing recycling rates and reducing waste sent to landfills, thereby reducing environmental impact and boosting the community's role in sustainability

5 Literature Review

Project Idea	Objective	Technologies Used	Contributors	Relevant Sources	Date	Type
AI-Powered Recycling Stations	Automate the sorting and recycling process at public stations.	AI (image recognition), robotics, IoT	MIT Senseable City Lab	AI-Driven Smart Bin for Waste Management (IEEE)	2021	Research Paper
Smart Composting Systems	Create automated composters for homes and industries to manage organic waste efficiently.	IoT sensors, AI, composting algorithms	Lomi by Pela (sustainable tech company)	Prioritized Intelligence of Things for Waste Management (PLOS ONE)	2020	Research Paper
Intelligent Water Conservation Systems	Monitor and optimize water usage in residential and agricultural settings.	IoT sensors, AI for data analysis	Irrigation Research Institute, USDA	IoT-Enabled Waste Systems for Smart Cities (IEEE)	2022	Research Paper
AI-Driven Urban Gardening Systems	Build self-sustaining gardens for urban areas with minimal human intervention.	IoT, AI, solar panels, water recycling	Vertical Field (agriculture tech company)	Robots in the Garden: Artificial Intelligence and Adaptive Landscapes (arXiv)	2023	Research Paper
Waste-to-Energy Optimization	Improve energy recovery from waste using AI-enhanced incineration systems.	AI, IoT, thermal sensors	Veolia Environment SA	Energy Recovery in Sustainable Waste Management Systems (Elsevier)	2019	Book
Real-Time Noise Pollution Mapping	Collect and analyze noise data in urban areas to identify and mitigate sources of noise pollution.	IoT noise sensors, AI for pattern recognition	WHO and UNEP	Environmental IoT for Noise Pollution Mapping (Springer)	2021	Research Paper
Smart Food Waste Management Systems	Use AI to manage and redistribute surplus food to reduce waste and hunger.	AI, IoT, cloud databases for coordination	Too Good To Go (anti-food waste app)	Innovative Food Waste Solutions (Elsevier)	2023	Book

Table 1: Overview of Literature Review Projects

6 Methodology and approach

1. Building Smart Containers:
   Equip waste containers with sensors to monitor the filling extent of the container and notify the collection center when it is filled
2. Adding AI for Sorting:
   - Using computer vision to sort waste and determine its type, such as plastic, paper, metal, etc.
   - Artificial intelligence system training using image data to optimize sorting accuracy.
3. Real-Time Monitoring:
   Using IoT-enhanced sensors to monitor container fill levels in real-time and alert the collection center when a container is full ensures timely unloading.
4. Route Optimization:
   Applying machine learning algorithms to analyse mobilisation level data and improve waste collection methods to reduce distances and costs.
5. Testing and Adjustments:
   Test the sensors and sorting system in many different conditions.
6. Monitoring and Improving:
   - Use the data to make waste collection more efficient.
   - Update AI models with new data for better sorting over time.

7 Equipment or Software

Equipment

1. Smart waste bins
   Bins made of weather-resistant materials designed to facilitate the sorting and transportation process

2. Sensors

   - Ultrasonic sensors
     These devices can measure the distance between the top surface of the waste and the top of the bin, allowing for accurate detection of the filling level. They are installed at the top of the bin and send signals to the central system when a certain filling level is reached. The reason for choosing ultrasonic sensors is that they are not affected by external factors, are easy to install at the top of the bins, and provide accurate measurements of the filling level
   - Load cell
     This weight sensor is used to determine the amount of waste in the bin. When the bins approach the maximum weight, it sends notifications to the waste collection center to alert the center to empty them.
   - Material sorting sensors
     Such as optical sensors and magnetic sensors that help distinguish between plastic (such as PET and HDPE), metals (such as aluminum) and paper

3. Advanced cameras

   - High-resolution cameras
     They are characterized by high resolution, which helps in classifying waste more accurately and facilitates the sorting process and identifying different types (such as plastic, paper and metals).
   - Thermal Cameras
     They can operate in low light conditions or even in complete darkness as they rely on the heat emitted from objects, which helps in monitoring containers even at night.

4. Communication Systems

   - Wireless technology that uses Wi-Fi technology to transmit data over wireless local area networks.
   - Long-range network: used to transmit data over long distances (up to several kilometers). They are designed to be energy efficient, allowing devices to operate for long periods without needing to be charged, and have a wide range, making them ideal for use in rural or remote areas where it may be difficult to obtain a Wi-Fi signal.

5. Aerobic Composting System

   A device that helps obtain high-quality fertilizer that can be used in agriculture or gardens, and reduces unpleasant odors resulting from anaerobic decomposition.

Software

1. Machine Learning and Artificial Intelligence Software:
   TensorFlow: For developing deep learning models.
   PyTorch: For developing deep learning models.
   OpenCV: For image and video processing.

2. Data Analysis Software:
   Pandas: For data analysis and processing.
   NumPy: For mathematical operations and numerical processing.
   Matplotlib: For visualizing data.
   Seaborn: For improving charts.

3. Data Management Systems:
   SQLite: A lightweight database for storing data.

4. Communication Tools:
   Twilio:for sending text messages and alerts.

5. Programming Tools:
   PyCharm or Visual Studio Code: Integrated Development Environments (IDEs).

6. Cloud Tools:
   Google Cloud AI: Cloud services for artificial intelligence.

It is important to a maintenance system in place to ensure performance, avoid sudden failures, improve equipment lifespan, and provide continuous updates.

8 Ethics and bias

1. Fairness and Inclusivity:

   AI-based systems can propagate biases in the categorization of wastes if the training dataset is not representative of diverse wastes. To mitigate these:

   - Diverse datasets will be used to train the AI sorting system, ensuring that it can accurately handle various waste materials.
   - There would be continuous monitoring and evaluation so as to identify and rectify biases falling in the system.

2. Environmental Impact:

   While it is designed to reduce waste and increase recycling, the manufacturing process and eventual maintenance of smart containers themselves may have environmental impacts. To minimize this:

   - Sustainable Materials: Containers will be made from either recycled or durable, eco-friendly materials to reduce the exhaustion of resources. Materials will be chosen for their longevity, having the least possible impact on the environment, such as stainless steel or biodegradable plastics for particular parts.
   - Energy Efficiency: Sensors will use low-power technology to reducing overall power consumption, and containers will integrate small solar panels to power the sensors and AI systems, ensuring a sustainable energy source. The technology will include energy-saving modes that activate only when needed, further minimizing energy usage

3. Transparency and Accountability:

   It is important to ensure transparency in how AI decisions are made, particularly in the waste sorting process. To uphold transparency:

   - Regular audits will be performed to ensure system performance and reliability.

4. Data Privacy and Security:

   Waste containers will collect and transmit data on fill levels and waste types. This raises potential concerns regarding data security and privacy. To address this:

   - Access to data will be strictly filtered to personnel on a need-to-know basis using secure protocols.
   - Stakeholders will be informed of a clear privacy policy.
   - Fair and equitable use of AI: In the sense that the technology will treat all categories of waste materials equally without promoting specific ones. Regular reviews will be made to ensure that AI operates without bias.

9 Limitations

1. Technological Challenges:

   - Sensor Accuracy:

     Sensors can have difficulties with the correct detection of fill level or with waste type recognition in specific conditions, such as mixed waste.

     – These issues would be overcome by regular calibration and updating of sensor technologies. An error-detection system would flag mixed wastes for manual inspection or further processing.

   - AI Sorting Challenges:

     The sorting system may struggle with unfamiliar or composite waste materials.

     – The AI models will need to be constantly retrained with updated datasets for improved sorting accuracy.

   - Mixed Waste Handling:

     The system may encounter waste that is difficult to sort automatically, potentially leading to inefficiencies.

     (a) Using advanced cameras and AI-based image processors to accurately identify various types of mixed waste. The system is trained with image data of different waste types.
     (b) Sort out items in stages, sorting the bigger items first and leaving the smaller, more complicated materials to the end.
     (c) Transferring materials that are difficult for the system to sort to manual sorting.
     Continuous updates to the AI will help reduce such occurrences over time.

2. Environmental and Operational Challenges:

   - Weather Conditions:

     Sensors could malfunction due to exposure to harsh weather conditions, such as extreme heat, rain, or sandstorms.

     (a) Use sensors with a high IP (Ingress Protection) rating to endure severe weather such as rain, sandstorms, and high temperatures.
     (b) Regularly maintain the devices, ensure their safety, and update the software used by the sensors to enhance their performance.
     (c) The sensors are housed in protective boxes for long-term performance.

   - Maintenance Requirements:

     Regular upkeep of sensors and AI systems is necessary, leading to ongoing costs.

     – Maintenance protocols and cost-sharing models will be developed to ensure operational continuity.

   - Cultural Sensitivity:

     Waste management practices and types of waste differ among regions, so a one-size-fits-all approach may not work.

     – The system will be adaptable to different cultural and regional contexts.

- Data Privacy and Security:

  Collection and transmission of data about fill levels and types of waste can be a concern for privacy.

  (a) Data encryption and access control, making it available only to those people who are supposed to access the data.
  (b) Ensure transparency in data collection and usage by creating a privacy policy that outlines how data is collected, stored, and utilized.
  (c) Observe ethical standards and follow the privacy laws.

10 Conclusion

The implementation of smart waste containers in Saudi Arabia represents a significant step forward in waste management and environmental sustainability. With the incorporation of sensors and AI technologies, this system will enhance waste collection efficiency, reduce the costs associated with it, and promote recycling. It supports the goals of Saudi Arabia's Vision 2030 by fostering cleaner cities and a more sustainable environment for future generations.

11 Visual Summary Figure

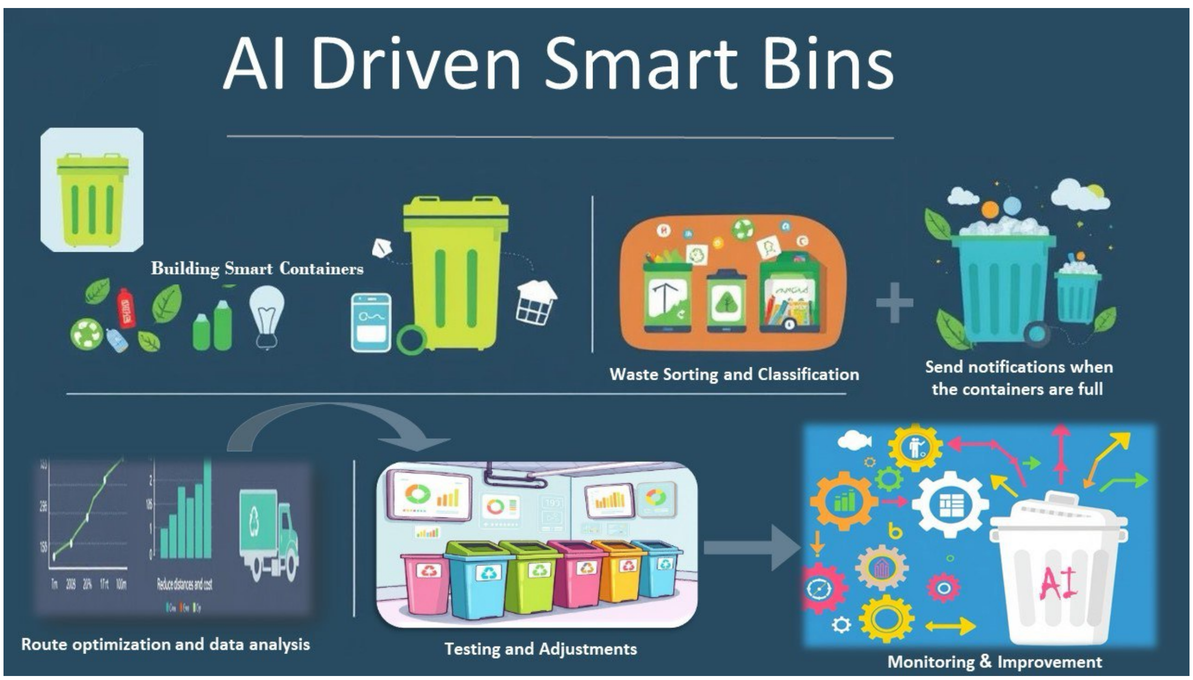

Figure 1: Summary Figure