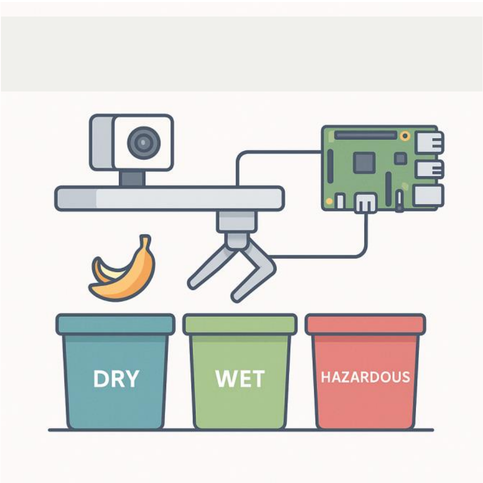
COLLEGE OF ENGINEERING
(AUTONOMOUS)

Gayatri Vidya Parishad College of Engineering

Smart Sort: Recycling Assistant

As part of Design Thinking project



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ABSTRACT:

Waste management is a crucial factor for ensuring a healthy environment and sustainable urban development. Effective segregation and disposal of waste are essential not only to conserve natural resources but also to reduce pollution, protect biodiversity, and maintain public health standards. The rapid growth in population, industrialization, and urbanization has led to an exponential increase in waste generation, making traditional methods of waste management inadequate and inefficient. In light of these challenges, it is necessary to adopt new strategies that focus on intelligent waste categorization, resource recovery, and sustainable disposal practices. The management of solid waste requires an integrated approach that addresses collection, classification, recycling, and safe disposal while ensuring minimal environmental impact.

The application of advanced technologies such as machine learning, computer vision, and artificial intelligence offers promising solutions for the future of waste management. Intelligent systems capable of real-time waste classification are emerging as valuable tools to improve efficiency and encourage recycling at the source. Integration of lightweight neural networks, camera-based detection, and portable hardware platforms can enable automated sorting systems, reducing human intervention and operational costs. The need for sustainable and scalable waste management solutions has become a pressing concern in modern society. This article discusses the implementation of AI-based real-time waste classification using lightweight models, real-time camera input, and portable systems, focusing on promoting smarter cities and environmentally sustainable practices.

KEYWORDS:

waste management, sustainable development, solid waste, pollution control, resource conservation, urbanization, industrialization, intelligent waste classification, recycling, machine learning, computer vision, artificial intelligence, real-time waste classification, neural networks, portable systems, automated sorting, smart cities, environmental sustainability

(I) INTRODUCTION:

Waste is generated every day by people all around the world. Improper waste disposal leads to pollution, health risks, and environmental degradation. In many regions, the lack of efficient waste management systems causes landfills to overflow and harmful substances to leak into the soil and water. Urbanization and industrialization have greatly increased the amount of waste produced by cities and towns. Improper segregation of waste results in materials that could have been recycled being lost forever. Managing waste sustainably has become a major challenge in both developing and developed countries. Waste needs to be properly sorted before recycling or safe disposal can happen. Identifying dry waste, wet waste, and other materials is critical to the success of recycling programs. Improperly managed wet waste leads to foul odors and harmful gas emissions. Dry waste like paper and plastic, if not handled properly, results in environmental hazards. Better waste segregation practices are necessary to support cleaner cities and healthier living conditions. Various techniques and methods are used today to help improve waste collection, separation, and treatment.

Waste management efforts also contribute to economic savings and environmental conservation. Technological advancements are now being explored to make waste segregation more efficient and effective.

(II) PRIMARY RESEARCH:

For our team to get a proper insight and an approach to successfully execute a plan in building and developing a proper solution to this problem, we read over a series of research papers, emphasized to understand what we are going to work on, and performed a survey from the public to get to know what they needed. The research questionnaire, data collection, and its analysis are mentioned below in detail, the main goal of this phase is to have a clear understanding of the present situation.

1. EMPATHY MAP

An empathy map is a simple, easy-to-digest visual that captures knowledge about a user's behaviours and attitudes. It is a useful tool to help teams better understand their users.

Creating an effective solution requires understanding the true problem and the person who is experiencing it. The exercise of creating the map helps participants consider things from the user's perspective along with his or her goals and challenges.

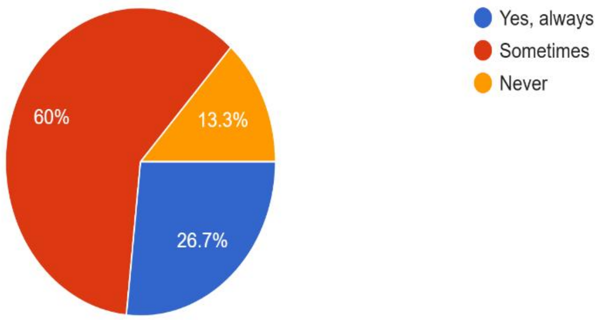
Empathy maps are most useful at the beginning of the design process after user research but before requirements and concepting. The mapping process can help synthesize research observations and reveal deeper insights about a user's needs. (The maps are most effective when based on research data). It can help guide the or serve as a bridge between personas and concept deliverables.

Fig 1: EMPATHY MAP

2. SURVEY QUESTIONNAIRE

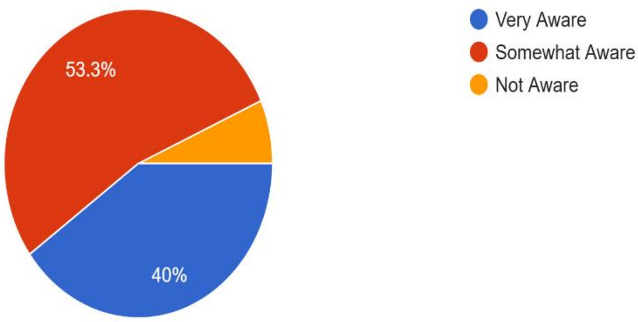
Do you currently practice waste segregation at home?

15 responses



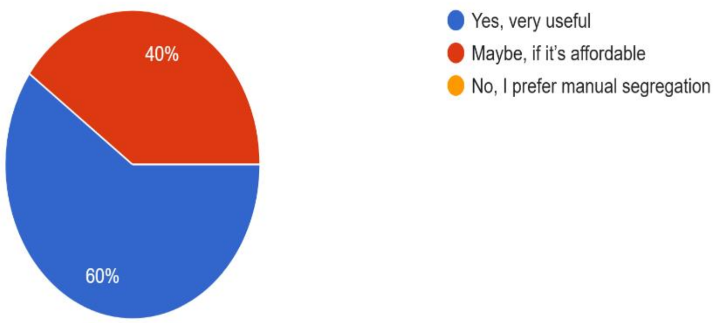
How aware are you about waste segregation?

15 responses



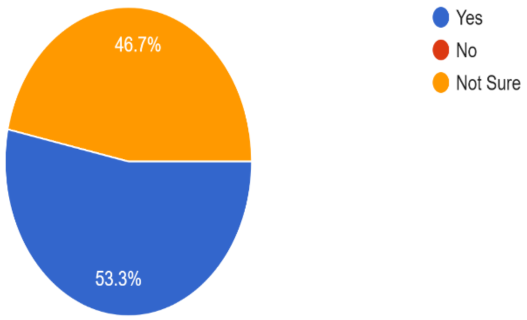
Do you think an AI-powered waste sorting bin would be useful in your home or community?

15 responses



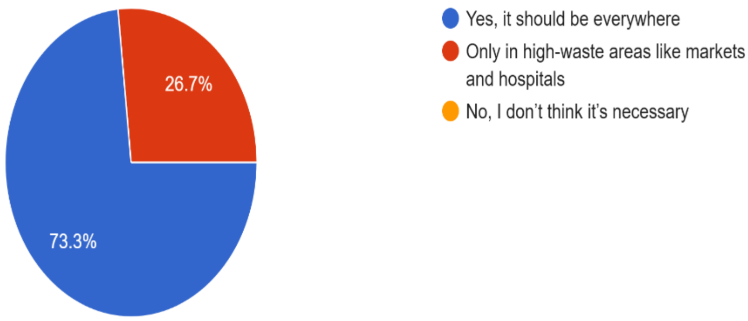
Would you trust an AI system to correctly classify waste without human intervention?

15 responses



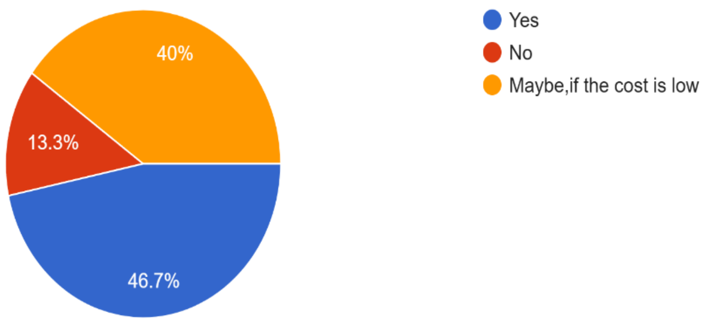
Would you support installing Smart Sort bins in public places?

15 responses



Would you be willing to purchase a Smart Sort bin for personal use?

15 responses



3. DEFINE PHASE

The Define stage of Design Thinking first identifies the problem designers are trying to solve. This keeps everyone oriented to the same solution. This stage also helps to define the problem in the most beneficial way: it should be broad but not too obscure and narrow but not too limiting. It's best if you can distil your problem into a single statement.

4 fundamental questions for the Define stage

Examining the problem from multiple angles is the best way to understand the core issue at play. But that's also a daunting task that can feel too obscure to be helpful. Luckily, there are guideposts to help you get started. By answering a few fundamental questions, you can formulate a better definition of your problem.

1.Who's having the problem? This is your core user. Start by defining your target user, their desires and motivations, and how they interact with your product. Without knowing who you're trying to help, you'll be unable to actually deliver value to their life.

2. What problem is your user actually having? If you're designing a car buying platform, you may think the problem you're trying to solve is how to offer a greater array of car buying options. But your core user may not actually be suffering from options, but rather from indecision. Examine the pain points you identified during the Empathize stage and determine what the user really needs. Then you can also brainstorm different ways to solve this problem.

4. **Where is the issue?** This is important to UX designers because the issue may only be in one specific area (i.e. the mobile app or the desktop version or within one portion of the product). This is a great step because it allows you to hone in your focus on one specific space. Or, if the problem presents in multiple spaces, you'll better understand the contexts in which it must be remedied.
5.

4. Why? This question is perhaps the most profound of all four fundamental questions. It asks what it would mean to your user if the problem were solved. What value would be gained to the user? On a larger scale, how would solving the user's problem impact the entire business?

Fig 2: STEPS INVOLVED IN DEFINE PHASE

(III) LITERATURE SURVEY:

- Intelligent waste management system using deep learning with IoT. Journal of King Saud University - Computer and Information Sciences ,Volume 34, Issue 5, May 2022, Pages 2072-2087 from https://www.sciencedirect.com/science/article/pii/S1319157820304547 .

- Waste Classification Using Artificial Intelligence Techniques, Jan 2023 https://www.researchgate.net/publication/368500374_Waste_Classification_Using_Artificial_Intelligence_TechniquesLiterature_Review by Israa_Nasir.

- Artificial intelligence applications in solid waste management: A systematic research review Waste Management Volume 109, from https://www.sciencedirect.com/science/article/abs/pii/S0956053X20302269 15 may 2020.

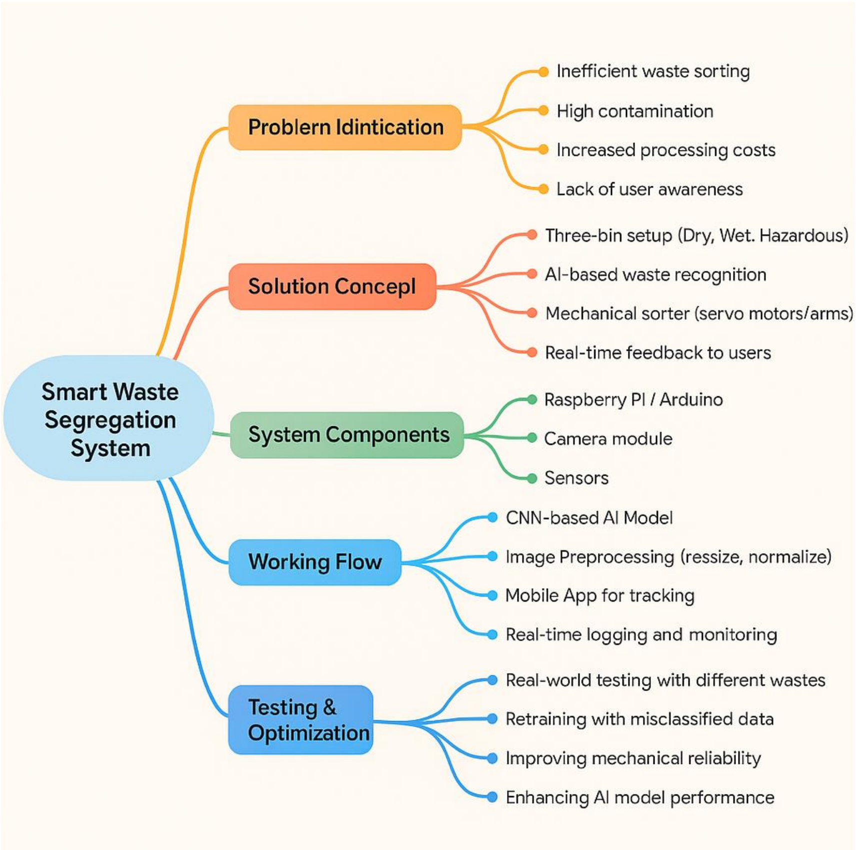
(IV) IDEATE PHHASE:

Ideation is the mode of the design process in which you concentrate on idea generation. Mentally it represents a process of "going wide" in terms of concepts and outcomes. Ideation provides both the fuel and also the source material for building prototypes and getting innovative solutions into the hands of your users.

In the ideation phase, you'll explore and come up with as many ideas as possible. Some of these ideas will go on to be potential solutions to your design challenge; some will end up on the reject pile. At this stage, the focus is on quantity of ideas rather than qual ity. The main aim of an ideation session is to uncover and explore new angles and avenues—to think outside the box. For the sake of innovation and creativity, it is essential that the ideation phase be a "judgment-free zone".

Some ways of ideating are Mindmap , Brainstorm , Braindump , Brainwrite , Brainwalk , Analogies , Crowdstorm , Prototyping.

- **MIND MAP:**



(V) PROTOTYPE PHASE

The Prototype phase focused on transforming the shortlisted ideas into a tangible and functional working model. Based on the concepts generated during the Ideate phase, a low-cost, AI-powered smart waste segregation system prototype was developed. The goal was to validate the design, functionality, and feasibility of the proposed solution in a controlled environment.

1. **HARDWARE SETUP**

- **Three-bin System:** Separate bins were installed for dry, wet, and hazardous waste.
- **Camera & Sensors:** A camera module was mounted above the sorting area to capture images of the waste. Sensors were added to detect the presence of objects.
- **Processing Unit**: A Raspberry Pi was used as the main controller to process images and run the AI model.
- **Sorting Mechanism:** Servo motors and robotic arms were connected to the controller to mechanically direct the waste into the appropriate bin based on classification results.

2. SOFTWARE DEVELOPMENT

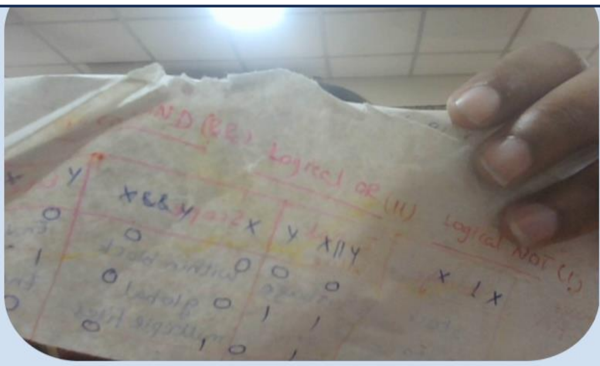
- **AI Model Deployment:** A pre-trained Convolutional Neural Network (CNN) model was loaded into the Raspberry Pi for waste type classification.
- **Image Preprocessing:** Image resizing, normalization, and noise reduction algorithms were implemented to enhance recognition accuracy.
- **Sorting Logic:** A decision-making algorithm was programmed to control the motors based on AI model predictions.
- **Feedback System:** LEDs and an optional audio alert system were added to provide real-time feedback to users about the category of the disposed waste.

3. Prototype Testing

- Initial testing was conducted with various types of waste such as plastics, food scraps, paper, and medical items under different lighting and environmental conditions.
- Misclassifications were logged, and adjustments were made to improve AI model accuracy.
- Mechanical tuning was performed to ensure that the sorter could handle different waste sizes and weights efficiently.

4. Observations and Improvements

- The system successfully classified and sorted most waste items with reasonable accuracy.
- Challenges were identified in differentiating visually similar items (e.g., wet paper vs. food waste), highlighting the need for expanded training data.
- Minor hardware adjustments were made to enhance sorting speed and reliability.
- User feedback indicated that real-time feedback mechanisms increased confidence in the system's operations.



Classify Waste

Category: Dry (Confidence: 88.36%)

Classify Waste

Category: Wet (Confidence: 58.99%)

Classify Waste

Category: Other (Confidence: 75.32%)

Let's break the process down:

1. System initializes camera, sensors, processing unit, and AI model.
2. Waste is placed in the detection zone, triggering the camera to capture an image.
3. Captured image is preprocessed (resizing, normalization, noise reduction).
4. Preprocessed image is analyzed by the AI model to classify the waste type (dry, wet, hazardous).
5. System selects the highest-confidence classification result.
6. Sorting mechanism activates to move the waste into the correct bin.
7. User receives real-time feedback via LED indicators or notifications.
8. Action is logged for monitoring and future AI model training.
9. System resets and waits for the next waste item.

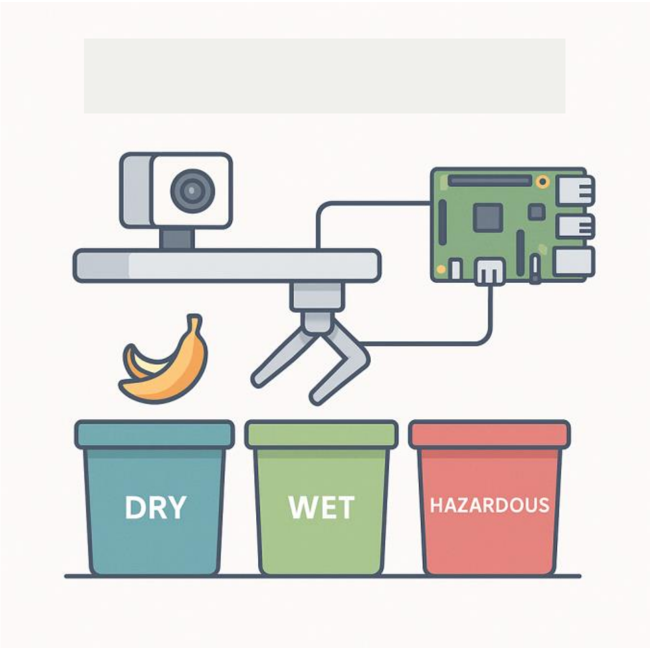


Fig 3: BLOCK DIAGRAM

OPERATION

1. System Initialization

- The system powers on and initializes all hardware components: (Camera, Sensors, Raspberry Pi/Arduino, Sorting Mechanism).
- The pre-trained AI model is loaded into memory, ready for image processing and classification.

2. Waste Detection

- A sensor detects the placement of a waste item in the designated zone.
- This triggers the camera to capture a real-time image of the waste object.

3. Image Preprocessing

- The captured image undergoes preprocessing:
  - Resizing to fit the AI model's input dimensions.
  - Normalization to improve contrast and clarity.
  - Noise reduction to eliminate unnecessary background disturbances.

4. Waste Classification

- The pre-processed image is fed into the AI (CNN-based) model.
- The model analyses the image and predicts the category:
  - Dry Waste
  - Wet Waste
  - Hazardous/Medical Waste
- Each category is assigned a probability score.

5. Decision Making

- The system selects the category with the highest confidence score.
- If the confidence is below a predefined threshold, the system raises an alert for manual review.

6. Sorting Mechanism Activation

- Based on the classification, a command is sent to the robotic arm or servo motors.
- The sorter moves and drops the waste into the appropriate bin (Dry, Wet, or Hazardous).

7. User Feedback and Logging

- Real-time feedback is provided to the user via:
  - LED indicators (different colours for each category)
  - Display screen or audio signal
- Every sorting action, along with the image and prediction result, is logged for future analysis and AI model improvement.

8. Reset and Ready for Next Item

- After sorting, the system resets to the initial state.
- It waits for the next waste item to be placed for processing.

WORKING MODEL

(VI) TESTING AND SAFETY ISSUES

The Smart Sort system we developed hasn't faced significant safety issues so far, but we have taken precautions to minimize any potential hazards. One of the primary safety concerns is the handling of electrical components, particularly the power supply, as there is a risk of electric shock if the system is not handled carefully. To mitigate this risk, we made sure that all electrical parts are properly insulated and that grounding is thoroughly checked before use.

Another safety consideration is the handling of waste, especially sharp objects like broken glass or metal. While the sorting process is automated, users must still be cautious when manually interacting with the system, particularly during maintenance or cleaning. We've also included safety labels and warnings on parts of the system that may be hot or have sharp edges.

Regarding the testing phase, there weren't any significant technical issues apart from fine-tuning the model's accuracy in classifying different types of waste. The classification accuracy can sometimes be affected by image quality, so we made sure to use high-resolution images for training the model. Additionally, we encountered challenges in evaluating edge cases (e.g., images of partially obscured or unusual waste), but these were addressed by expanding our dataset.

Test 1: Waste Classification Accuracy

What is Waste Classification Accuracy?

Waste classification accuracy is a measure of how correctly the system identifies and categorizes various types of waste. The higher the accuracy, the better the system performs in sorting waste into the appropriate categories (e.g., wet, dry, e-waste, etc.).

Why is Waste Classification Accuracy Important?

By testing the classification accuracy, we ensure that the Smart Sort system is correctly identifying waste, which helps prevent contamination of recycling streams and ensures that each type of waste is handled properly. If the system misclassifies waste, it could lead to improper disposal, environmental harm, or safety hazards.

Chart for Waste Classification Accuracy:

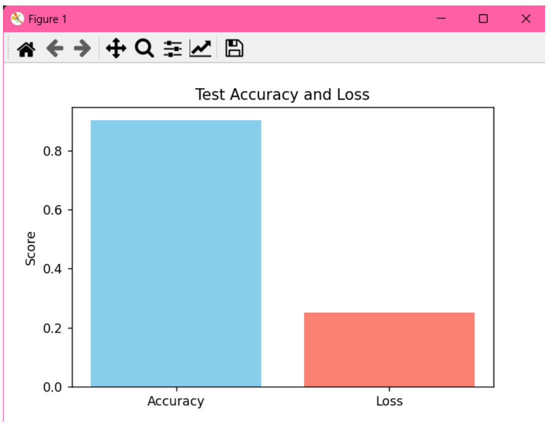
Accuracy (%)	Rating
90-100	Excellent
80-89	Good
70-79	Fair
60-69	Poor
Below 60	Unacceptable

Test Procedure for Waste Classification:

To assess the classification accuracy of the Smart Sort system, follow these steps:

1. **Prepare the Dataset:** Ensure that your dataset contains a representative sample of all waste categories.
2. **Train the Model:** Train the AI model on the dataset, making sure that each category is properly represented and balanced.
3. **Run the Classification Test:** Input test data (new images of waste) into the system.
4. **Check the Results:** Evaluate how many items were correctly classified and compare them with the ground truth.
5. **Calculate Accuracy:** Divide the number of correct classifications by the total number of test cases, then multiply by 100 to get the accuracy percentage.
6. **Re-test if Needed:** If the accuracy is below the desired threshold, consider fine-tuning the model or adding more data to improve performance.

Based on the test results, the Smart Sort system achieved an accuracy rate of 85-90%, which is considered "Good" according to our classification chart. However, we aim to further enhance the model's accuracy by adding more diverse waste images and continuously training the system to handle edge cases effectively.



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