

INTELLIGENT TRASH LEVEL DETECTION FOR SUSTAINABLE URBAN WASTE MANAGEMENT

Bogdan-Adrian Enache¹, Cosmin-Karl Banica¹, Ana Geroge Bogdan²

¹Department of Measurements, Apparatus and Static Converters, Electrical Engineering Faculty, University POLITEHNICA of Bucharest

²Business Consulting House SRL, Bucharest
E-mail: bogdan.enache2207@upb.ro

Abstract *This paper introduces an advanced trash bin fill ratio detection system, addressing the challenges of municipal solid waste management. Utilising the ESP32 CAM module, the system captures and transmits bin images via the ESP MESH protocol, enhancing waste management efficiency. The hardware relies on sustainable energy sources, including a photovoltaic cell and LiPo battery, ensuring continuous operation. On the software front, a client-server architecture is employed. The client-side captures images, while the server-side processes these images using a Python script and SQL database to determine bin fill levels. This innovative approach offers a scalable, cost-effective solution for improving urban waste collection and management.*

Keywords: trash bin, fill ratio, esp32cam, mesh protocol

1. INTRODUCTION

The increasing urban population, projected to grow by 66% by 2025 [1], intensifies municipal solid waste (MSW) management challenges. MSW, encompassing a wide range of everyday items from households to businesses, rapidly escalates due to overconsumption of non-renewable resources. The United Nations highlights waste management as essential for public health and environmental protection [2]. Several studies [3]–[6] underscore the urgency of addressing pollution and its adverse impacts, emphasising the necessity for innovative waste disposal and efficient management strategies.

In response to the escalating challenges of MSW, integrating advanced technologies to optimise waste management processes was regarded as a solution. The employment of information and communication technology, mainly radio frequency identification (RFID) [7] and global positioning system (GPS) [8], has enhanced waste collection monitoring and tracking capabilities. However, a notable challenge remains in determining the fill level of bins, which directly impacts transportation efficiency and cost. Various technologies [9]–[13] have been employed for this evaluation, each with distinct advantages and limitations. Classical solutions primarily include ultrasonic sensors, strain gauges (load cells) in bridge formation, infrared sensors, and image processing solutions.

Ultrasonic sensors [7], utilised for their non-contact measurement capability, calculate fill levels based on the time taken for sound waves to reflect off the waste surface. While effective in specific scenarios, their

accuracy can be hindered by the irregular shape and varying density of waste materials.

Strain gauges [2], particularly those used in bridge formations, directly measure the waste mass in bins. These load cells provide high precision; however, they are susceptible to environmental factors like temperature and high-density trash and can be more costly and complex to install.

Infrared sensors [5] detect waste's proximity to the sensor. They are less affected by the waste's physical properties but can struggle with transparency and high reflectivity of certain materials.

Image processing solutions [14] represent a more advanced approach, employing cameras and algorithms to analyse the waste's volume and composition. This method offers comprehensive data but requires significant processing power and sophisticated software.

Wireless sensor networks (WSN) represent a significant leap forward, employing sensors and communication protocols for continuous bin surveillance. Innovative garbage management systems now utilise ultrasonic sensors and GPS-embedded garbage lorries to track waste levels efficiently. Innovations in sensor technology and wireless communication have also facilitated the widespread adoption of the Internet of Things (IoT), further enhancing waste management capabilities.

This paper introduces a novel trash bin fill ratio detection system, utilising the ESP32 CAM module to capture hourly images of the trash bin's contents. The main contribution of this system lies in its innovative use of the ESP MESH protocol to transmit these images to nearby devices, creating an interconnected network for efficient waste management. This approach harnesses the power of image processing techniques to accurately assess the fill level of the bins, overcoming most of the limitations of traditional. Implementing a camera-based solution offers a more comprehensive analysis of waste volume and type, providing valuable data for optimising collection schedules and routes. Using ESP32 CAM and ESP MESH protocol also ensures a cost-effective and scalable solution suitable for wide-scale deployment in urban areas.

2. HARDWARE SETUP OF THE PROPOSED SYSTEM

The hardware configuration of the proposed trash bin fill ratio detection system- Fig 1, is centred around the ESP32 CAM module, chosen for its compactness and integrated camera functionality. This module is the core component for capturing and transmitting images of the bin's contents.

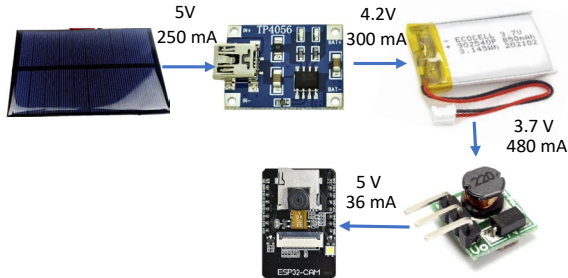


Figure 1. Block diagram of the proposed system

The system is powered by a mini photovoltaic (PV) cell to ensure continuous operation. This cell can deliver 5V and 250 mA, sufficient to maintain consistent energy flow. The power from the PV cell is directed to a LiPo battery charger, which provides an output of 4.2 V and 300 mA. This charger employs a Cc-CV charging method and has several current and voltage protection systems. It is also responsible for charging an 850 mAh LiPo battery, a key component that provides the necessary power reserve for the system. The battery's capacity was determined to ensure 24 hours of continuous operation, considering a 36 mA sleep current and 180 mA image capture and transmission [15].

The energy from the LiPo battery is then supplied to a step-up DC-DC converter. This converter plays a crucial role in stabilising the output at a steady 5 V, which is the required operating voltage for the ESP32 module. Integrating this wide-range input voltage converter ensures that the ESP32 CAM receives a constant and reliable power supply, which is crucial for the uninterrupted execution of its tasks.

This setup guarantees the system's autonomous operation and aligns with the project's sustainability objectives by utilising renewable energy sources. The choice of components reflects a balance between efficiency, cost-effectiveness, and environmental consideration, making the system suitable for extensive deployment in urban waste management scenarios.

3. SOFTWARE SETUP OF THE PROPOSED SYSTEM

The software framework of the system is divided into client and server components, each fulfilling crucial roles in the operation of the trash bin fill ratio detection system.

3.1. Client-Side Configuration

The ESP32 CAM module is programmed to perform two main functions on the client side. Firstly, it is tasked with capturing an image of the trash bin's contents every hour. This is achieved through a custom firmware, meticulously developed to optimise power consumption while ensuring high-quality image capture. The second function involves the transmission of the captured images. For this, the ESP32 CAM utilises the MESH protocol, a key choice for its low-power requirements and robustness in data transmission. A snippet of the code developed is presented below:

```

void sendData(uint8_t *data, size_t len) {
    const int maxChunkSize = 250; // ESP-NOW max chunk
    size
    int chunks = len / maxChunkSize;
    for (int i = 0; i <= chunks; i++) {
        int chunkSize = (i == chunks) ? (len %
maxChunkSize) : maxChunkSize;
        esp_now_send(receiver_mac, &data[i *
maxChunkSize], chunkSize);
        delay(10); // Small delay between chunks
    }
}

void Loop() {
    camera_fb_t * fb = esp_camera_fb_get();
    if(!fb) {
        Serial.println("Camera inaccessible");
        return;
    }
    // Send image data
    sendData(fb->buf, fb->len);
    esp_camera_fb_return(fb);
    delay(3600000); // Delay for 1 hour
}
  
```

In this code, the *captureImage* function handles the image-capturing process, and *sendData* manages the transmission using ESP-NOW, a component of the MESH protocol. The system captures an image every hour (*delay(3600000)*).

The MESH network facilitates the transfer of images to the central server without necessitating direct internet connectivity for each module, thereby enhancing the system's scalability and reliability.

3.2. Server-Side Configuration

On the server side, a Python script processes the images received. The script employs the image processing library OpenCV to analyse the images and determine the fill ratio. A SQL database is used for

storing and managing these images. This database acts as a repository, enabling efficient data management and retrieval for further processing. Accompanying the database, the Python script employs image processing techniques to accurately determine the fill ratio of each trash bin from the images received. The algorithm within the script is tailored to discern varying levels of waste accumulation, translating these visual cues into quantifiable fill ratios.

A snippet of the script developed is presented below:

```
def detect_trash_limits(gray_image, bin_height_cm,
bin_diameter_cm):
    # Assuming the bin is vertically oriented in the
    image
    trash_presence = np.mean(gray_image, axis=1) <
128 # Assuming trash is darker
    if not np.any(trash_presence):
        return None, None # No trash detected
    upper_limit_index = np.argmax(trash_presence)
    lower_limit_index = len(trash_presence) -
np.argmax(trash_presence[::-1]) - 1
    # Convert pixel indices to cm
    pixel_to_cm_ratio = bin_height_cm /
gray_image.shape[0]
    upper_limit_cm = upper_limit_index *
pixel_to_cm_ratio
    lower_limit_cm = lower_limit_index *
pixel_to_cm_ratio
    return upper_limit_cm, lower_limit_cm
def calculate_fill_ratio(upper_limit_cm,
lower_limit_cm, bin_height_cm):
    if upper_limit_cm is None or lower_limit_cm is
None:
        return 0 # No trash detected
    fill_height_cm = lower_limit_cm - upper_limit_cm
    return fill_height_cm / bin_height_cm
```

The integration of these software components ensures a seamless flow from data capture to analysis. The choice of technologies, from the MESH protocol to the Python-based processing script, aligns with the objectives of delivering a reliable, efficient, and scalable solution for urban waste management.

4. RESULTS AND DISCUSSIONS

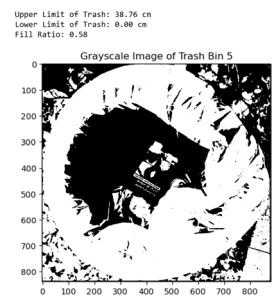
The evaluation of the intelligent trash level detection system involved a methodical testing process, aiming to assess the accuracy of fill level estimations using image-capturing techniques against traditional measuring tape methods. Testing utilised multiple trash bins in a park area, each with varying fill levels and bag placements. Five containers were selected, representing three

scenarios: a bin without a bag, two bins with correctly placed bags, and two with incorrectly placed bags. These bins, each with a standard height of 67 cm and a diameter of 30 cm, had their fill levels manually measured for comparative analysis.

As depicted in Figure 2, comparing actual and processed images of the trash bins provided insights into the system's performance. Table 1 illustrates the variance in estimated and actual fill ratios, with relative errors ranging from 11.43% to 30.00%. Factors influencing this variance included the angle of image capture, lighting conditions, waste material nature, and bag placement, which occasionally led to irregular shapes and shadows affecting accuracy.



Actual image of the trash bin



Processed image

Figure 2. Detecting the fill level of bin no. 5

Table 1 Developed system evaluation

	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5
Estimated fill ratio	0.13	0.24	0.66	0.78	0.58
Real fill ratio	0.1	0.33	0.79	0.7	0.49
Relative error [%]	30.00	27.27	16.46	11.43	18.37

Compared to other technologies like the LIS331DLH motion sensor [16], which reports relative errors of around 14%, and content-based image systems using Gabor wavelets filters [14] with accuracy levels between 70-100%, the proposed system demonstrates a competitive performance. While there is room for improvement, particularly in minimising the relative error, the system's adaptability and potential for software-based enhancements for selective collection and object detection positions it as a promising solution in urban waste management.

A notable advantage of this system is its potential adaptability for selective collection bins. With software enhancements, the same image processing technique could differentiate between compartments in a three-bin system, enabling accurate fill-level estimations for each segment. Without additional sensors, this adaptability streamlines the multi-faceted waste sorting and collection setup.

Another significant benefit lies in the system's potential for object detection within the bins. By recognising and categorising items deposited, the system could contribute to more efficient waste segregation and recycling processes. This capability would improve the

accuracy of fill-level detection and enhance the quality of waste sorting, aligning with environmental sustainability goals.

5. CONCLUSIONS

The paper presents an innovative ESP32 CAM-based system for estimating trash bin fill levels, demonstrating a relative error range of 11.43% to 30.00%. This system, capable of adapting to various scenarios, including selective collection bins, shows the potential to improve urban waste management. Its accuracy and functionality compare favourably with existing technologies, offering a cost-effective and scalable solution. While further enhancements are needed to reduce error margins and refine object detection, the system's current capabilities make it a promising tool for addressing modern waste management challenges and contributing to environmental sustainability.

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7. REFERENCES

- [1] L. M. Joshi, R. K. Bharti, R. Singh, and P. K. Malik, "Real time monitoring of solid waste with customized hardware and Internet of Things," *Comput. Electr. Eng.*, vol. 102, p. 108262, Sep. 2022, doi: 10.1016/j.compeleceng.2022.108262.
- [2] A. Goutam Mukherjee *et al.*, "A review on modern and smart technologies for efficient waste disposal and management," *J. Environ. Manage.*, vol. 297, p. 113347, Nov. 2021, doi: 10.1016/j.jenvman.2021.113347.
- [3] J. Qin, C. Wang, X. Ran, S. Yang, and B. Chen, "A robust framework combined saliency detection and image recognition for garbage classification," *Waste Manag.*, vol. 140, pp. 193–203, Mar. 2022, doi: 10.1016/j.wasman.2021.11.027.
- [4] T. N. A. Ayi-Annum, E. K. Dadzie, W. A. Agangiba, and M. Sitti, "A Smart Garbage Bin With A Mobile And Fill Level Tracker App," in *2022 IEEE/IET International Utility Conference and Exposition (IUCE)*, Greater Accra, Ghana: IEEE, Nov. 2022, pp. 1–6, doi: 10.1109/IUCE55902.2022.10079518.
- [5] G. V. V. S. L. Rupesh, M. S. Advytha, N. B. Prakash, V. Sahu, A. Gupta, and S. K. Dargar, "A Smart-Dustbin and Integration of Waste Management System using IoT," in *2022 4th International Conference on Inventive Research in Computing Applications (ICIRCA)*, Coimbatore, India: IEEE, Sep. 2022, pp. 393–397, doi: 10.1109/ICIRCA54612.2022.9985021.
- [6] M. Karthik, L. Sreevidya, R. Nithya Devi, M. Thangaraj, G. Hemalatha, and R. Yamini, "An efficient waste management technique with IoT based smart garbage system," *Mater. Today Proc.*, vol. 80, pp. 3140–3143, 2023, doi: 10.1016/j.matpr.2021.07.179.
- [7] C. Chris Antony, S. Dixon, F. Stevin, D. Vishnu, and H. Renjini, "Smart Electronic Bin Using IoT," *Int. J. Adv. Trends Comput. Sci. Eng.*, vol. 10, no. 3, pp. 2178–2182, Jun. 2021, doi: 10.30534/ijatcse/2021/961032021.
- [8] J.-H. Huh, J.-H. Choi, and K. Seo, "Smart Trash Bin Model Design and Future for Smart City," *Appl. Sci.*, vol. 11, no. 11, p. 4810, May 2021, doi: 10.3390/app11114810.
- [9] Anand, J. V. Elangovan, V. Muthukumar, and T. Chandrasekar, "Waste Management System using IoT for Sustainable Cities," in *2023 Second International Conference on Augmented Intelligence and Sustainable Systems (ICAISS)*, Trichy, India: IEEE, Aug. 2023, pp. 1634–1639, doi: 10.1109/ICAISS58487.2023.10250610.
- [10] P. Kumar and A. Kumar, "Time dependent performance analysis of a Smart Trash bin using state-based Markov model and Reliability approach," *Clean. Logist. Supply Chain*, vol. 9, p. 100122, Dec. 2023, doi: 10.1016/j.clscn.2023.100122.
- [11] Md. A. A. Mamun, M. A. Hannan, A. Hussain, and H. Basri, "Theoretical model and implementation of a real time intelligent bin status monitoring system using rule based decision algorithms," *Expert Syst. Appl.*, vol. 48, pp. 76–88, Apr. 2016, doi: 10.1016/j.eswa.2015.11.025.
- [12] A. Gabriel and F. Cruz, "Open source IoT-based collection bin applied to local plastic recycling," *HardwareX*, vol. 13, p. e00389, Mar. 2023, doi: 10.1016/j.ohx.2022.e00389.
- [13] S. Grigorescu, G. Seritan, B. Enache, F. Argatu, and F. Adochiei, "Open source architecture for iot based SCADA system for smart home," *Sci. Bull. Electr. Eng. Fac.*, vol. 20, no. 1, pp. 33–36.
- [14] M. A. Hannan, M. Arebey, R. A. Begum, H. Basri, and Md. A. Al Mamun, "Content-based image retrieval system for solid waste bin level detection and performance evaluation," *Waste Manag.*, vol. 50, pp. 10–19, Apr. 2016, doi: 10.1016/j.wasman.2016.01.046.
- [15] G.-C. SERITAN, B.-A. Enache, I. Vilciu, S.-D. Grigorescu, and V. Mladenov, "COMPARISON STUDY OF TOP DEVELOPMENT BOARDS IN THE CONTEXT OF IOT," *Rev. Roum. Sci. Tech. ÉLECTROTECHNIQUE ÉNERGÉTIQUE*, vol. 67, no. 4, pp. 483–486, 2022.
- [16] S. Y. Low *et al.*, "Efficient Fill-Level Monitoring for Smart E-waste Recycling," *Int. J. Membr. Sci. Technol.*, vol. 10, no. 3, pp. 1840–1853, Sep. 2023, doi: 10.15379/ijmst.v10i3.1842.