

Design and Research of TreatMate: A Smart Public Dog Food Vending Machine

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Peer Review Information	Abstract
<p>Type: Article Received: 27 March 2026 Revised: 12 April 2026 Accepted: 26 May 2026 Published: 16 June 2026</p>	<p>Urban regions face persistent challenges related to irregular stray-dog feeding, unmanaged plastic waste accumulation, and inconsistent access to controlled animal-food dispensing. This paper presents Treatmate, an IoT-enabled public dog food vending machine that integrates verified digital transactions with a recycling-oriented activation pathway to ensure controlled and incentivized food dispensing. The system is built around an ESP32 with an OV2640 camera module, while a Tiny CNN (96×96 input, quantized int8, TensorFlow Lite Micro) performs on-device bottle material classification to confirm whether the item inserted for recycling is plastic before rewarding the user. The dispenser uses a dual-actuation mechanism with a DC geared motor and servo motor, and real-time stock monitoring is provided through a load cell interfaced via an HX711 amplifier. A cloud-based backend developed using Node.js manages secure transaction validation, device synchronization, and centralized logging over HTTPS communication. In addition to automated dispensing, the system records recycling activity and feeding patterns within a centralized database. A dedicated analytics layer processes historical dispensing and bottle-insertion records to identify feeding trends and correlate food distribution with regional stray-dog demand. The proposed system demonstrates a scalable, sustainability-oriented smart infrastructure model integrating embedded vision, cloud computing, recycling incentives, and data driven urban welfare management.</p> <p>Keywords: IoT; ESP32; OV2640; Tiny CNN; TensorFlow Lite Micro; Embedded Systems; Smart Vending Machine; Load Cell Monitoring; Cloud-Based Control; Public Infrastructure Automation.</p>

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Introduction

The evolution of vending machines from standalone electromechanical systems to IoT-connected smart platforms [1] has significantly improved remote monitoring, device synchronization, and transaction management capabilities [2]. Integration of cloud computing and mobile-based digital payments has enabled cost-effective and user-friendly vending solutions across developing regions [3]. Modern vending architectures emphasize centralized monitoring, distributed control units, and modular firmware design to enhance reliability and scalability. These systems separate sensing, actuation, communication, and data-management layers to optimize performance, reduce maintenance complexity, and support multi-site deployment [4].

Treatmate extends established IoT vending principles by integrating verified QR-based transactions, plastic-bottle insertion incentives, real-time load-cell monitoring, and a cloud-based data science layer [5]. The system additionally introduces an embedded vision path in which the camera module verifies the inserted bottle material before the recycling reward is issued. [1]-[5] This allows the platform to correlate dispensing frequency, recycling participation, and stock utilization with regional stray-dog demand patterns, transforming conventional vending infrastructure into a socially impactful and data-driven urban welfare solution.

Overall System Architecture

Device Layer

The device layer forms the embedded hardware foundation of the system. It consists of the ESP32 microcontroller module, 12V DC geared motor, servo motor, relay module, strain-gauge load cell with HX711 amplifier, plastic-bottle detection pathway, OV2640 camera module, and a regulated power supply unit. This layer performs real-time sensing, actuation, and communication with the backend server. The ESP32 processes both transaction-based activation and bottle-insertion events, while the camera subsystem captures the incoming object for on-device verification. Upon receiving authorization from the backend or validating a bottle-detection signal, it controls motor actuation and dispensing operations. The load cell continuously monitors food stock levels, enabling dynamic tracking of dispensed and remaining quantities.

Vision-Based Recycling Verification

The recycling inlet is augmented with a camera-assisted verification stage to ensure that the returned container is actually plastic. When a bottle is inserted, the OV2640 camera captures the object at the inlet and the image is resized to 96×96 pixels for Tiny CNN inference[6]. The model is quantized to int8 and deployed using TensorFlow Lite Micro so that the classification runs locally at the edge with low memory footprint and reduced latency. If the frame is classified as plastic, the controller permits the recycling reward cycle; otherwise, the event is rejected and logged for review. This approach improves validation accuracy and prevents non-plastic waste from triggering a dispense cycle.

Cloud Layer

The cloud layer is implemented using a Node.js backend server with the Express.js framework, exposing RESTful API endpoints for structured communication. Secure HTTPS protocols ensure encrypted communication between the device and server. The backend verifies digital transactions via webhook confirmation and logs bottle-based dispensing events separately for sustainability tracking [7]. It manages device states, maintains synchronization, stores operational logs, and supports centralized monitoring of multiple deployed units. The cloud infrastructure ensures secure validation, data integrity, and scalable deployment across different regions.

Application and Data Intelligence Layer

This layer integrates user interaction, monitoring, and analytical processing. It includes a QR-based transaction interface, an administrative dashboard, and a centralized data-analytics module. The real-time database stores structured datasets including transaction records, plastic-bottle insertion counts, dispensing quantities, weight readings, timestamps, and system activity logs. A data-science component analyzes historical dispensing trends and bottle recycling activity to derive region-based feeding demand patterns. Time-series analysis and regression modeling correlate food dispensed with estimated stray-dog density in specific areas. Recycling participation metrics are also analyzed to assess environmental impact and community engagement.

Hardware Design

Microcontroller Unit

The system is built around the ESP32 selected for its integrated Wi-Fi capability, camera interface support, dual-core processing, and low-power operation[8]. It functions as the edge controller, managing transaction-validation signals, bottle-detection inputs, image capture, motor actuation, and sensor data acquisition.

Motorized Dispensing Mechanism

The dispensing mechanism employs a dual-actuation architecture for precision and reliability. A 12V DC geared motor drives the primary auger mechanism, enabling controlled bulk movement of food from the hopper. The motor is switched via a relay module controlled by an

ESP32 GPIO output, ensuring electrical isolation and protection against back-EMF. A servo motor regulates the dispensing gate using PWM signals from the ESP32. It provides precise angular positioning from 0° to 180°, ensuring controlled opening and closing of the outlet. The coordinated action of the DC motor and servo ensures calibrated portion control.

Weight Monitoring System

A strain-gauge load cell interfaced with an HX711 24-bit ADC continuously measures food stock levels. The HX711 amplifies microvolt-level signals and converts them into high-resolution digital values. Calibration algorithms implemented in firmware reduce measurement drift and enhance accuracy, enabling precise tracking of food dispensed and remaining inventory.

$$F = mg \tag{1}$$

The load cell operates based on $F=mg$ where the force exerted by the food mass produces strain in the sensor. This strain is converted into an electrical signal, which is calibrated to determine the weight, enabling accurate stock monitoring and dispensing measurement.

$$\varepsilon = \Delta L/L \tag{2}$$

The relation $\varepsilon=\Delta L/L$ defines strain as the ratio of change in length to the original length of the material. In the load cell, applied force causes a slight deformation (ΔL) in the strain gauge, and this strain is used to generate an electrical signal for weight measurement.

Camera-Assisted Bottle Material Classification

A camera-assisted verification module is used during recycling mode to determine whether the inserted container is plastic. The OV2640 camera captures the incoming bottle, and a Tiny CNN operating at 96×96 input resolution performs the classification using int8 quantization on TensorFlow Lite Micro. By running the inference locally on the ESP32, the system avoids unnecessary cloud round trips and keeps the response time low. The module can therefore separate plastic bottles from non-plastic objects before the dispensing reward is released [9]. The captured image from the OV2640 camera is represented as:

$$I \in R^{H \times W \times C} \tag{3}$$

The expression represents an image as a matrix of pixel values with height H , width W , and C color channels. In this project, the camera captures an image (e.g., 96×96×3), which is used as input to the CNN for plastic bottle detection.

$$F_{i,j,k} = \sum_{m,n,c} I_{i+m,j+n,c} \cdot K_{m,n,c,k} + b_k \tag{4}$$

The equation represents the convolution operation in a CNN. It computes each output feature by applying a filter (kernel) over the input image to extract patterns like edges and textures. In this project, this operation helps the model identify visual features of plastic bottles from camera images.

Power Management

The system operates on a regulated 12V supply for motor actuation and a stable 5V/3.3V supply for logic circuits. Proper grounding architecture, decoupling capacitors, and noise-filtering techniques are implemented to minimize interference, particularly in load cell signal acquisition. Electrical isolation enhances reliability and operational safety.

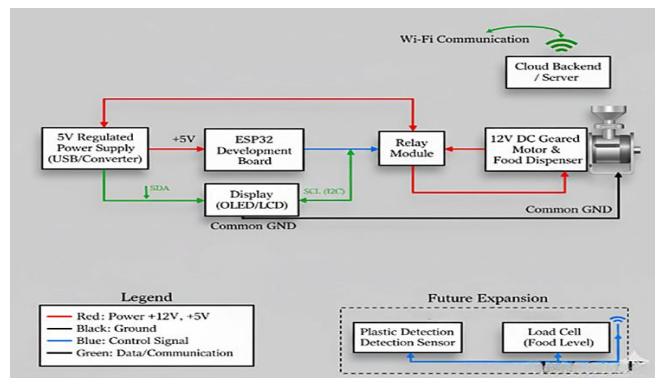


Fig. 1. Circuit diagram of the Treatmate system.

Software Design

Firmware Architecture

The firmware is developed using Arduino IDE in C/C++ and deployed on the ESP32. It performs Wi-Fi initialization, secure HTTP communication, JSON parsing, backend polling, image capture, and GPIO-based motor control. It also monitors bottle-detection inputs,

runs the Tiny CNN inference pipeline for bottle-material classification, and acquires load-cell data via the HX711 interface. The logic ensures that dispensing occurs only after successful transaction verification or validated bottle insertion. Sensor readings and activation events are transmitted to the backend in real time for logging and analytics.

Vision Inference Pipeline

The vision pipeline captures the frame from the OV2640 module, crops or normalizes the region of interest near the bottle slot, and resizes the image to the model input size of 96×96 pixels. The quantized int8 Tiny CNN is then executed through TensorFlow Lite Micro on the microcontroller. This edge-based design is particularly suitable for low-power deployments because it reduces memory consumption while keeping the recycling decision local to the device[10].

Backend System

The backend is implemented using Node.js with Express.js. It verifies digital transactions via webhook confirmation and authorizes dispensing upon successful validation. Bottle-based activations are logged independently to track sustainability metrics. RESTful API endpoints enable secure communication between the device and server using HTTPS encryption. The backend maintains device-state management, operational logging, and centralized synchronization for scalability.

Data Management and Analytics Layer

The centralized database stores structured datasets including transaction records, bottle-insertion counts, dispensing quantities, weight readings, image-classification outcomes, and timestamped logs. The monitoring dashboard, developed using HTML5, CSS3, and JavaScript, provides real-time visualization of machine status, stock levels, recycling activity, and transaction frequency. A data-science module analyzes historical dispensing and recycling data using time-series modeling and regression analysis. By correlating food dispensed and bottle-based activations with geographic location and time intervals, the system estimates stray-dog feeding demand patterns. Predictive analytics support optimized refill scheduling, deployment planning, and resource allocation.

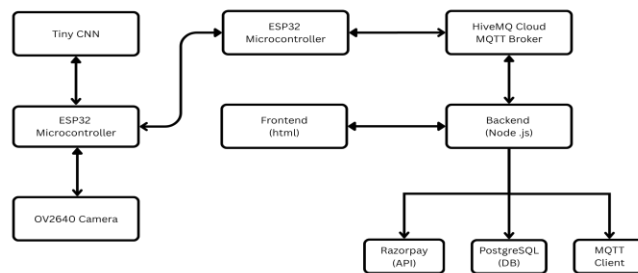


Fig. 2. Cloud backend and device communication architecture.

System Operation Flow

The operational sequence begins when a user scans the QR code displayed on the machine, initiating a digital transaction through a secure payment interface. Upon transaction completion, the backend server receives confirmation via webhook and records the event. The ESP32 polls the backend to verify authorization and, upon validation, activates the relay module to power the DC geared motor while simultaneously controlling the servo motor to open the dispensing gate for calibrated food release[11-13].

In recycling mode, when a plastic bottle is inserted into the designated entry channel, the camera-assisted verification stage captures the object and the Tiny CNN confirms whether the container is plastic. If the object passes validation, the controller initiates a controlled dispensing cycle similar to transaction-based activation. During and after dispensing, the load cell updates stock levels via the HX711 amplifier. All transaction events, bottle-based activations, dispensing logs, image-classification results, and weight data are stored in the cloud database. These datasets are processed by the analytics layer to monitor feeding trends and regional stray-animal demand patterns, enabling data-driven operational management [14-16].

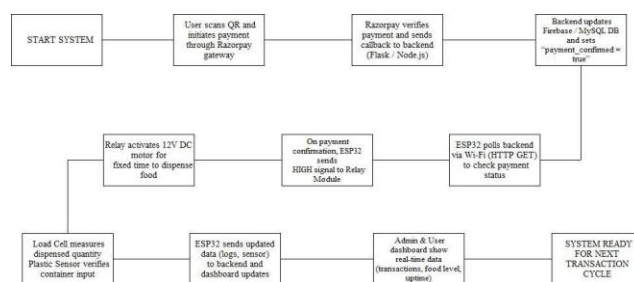


Fig. 3. End-to-end operation flow of the Treatmate dispensing cycle.

Results

The performance and operational behavior of the proposed Treatmate system were evaluated using real-time and simulated datasets obtained from dispensing logs, plastic bottle insertions, and load cell-based stock monitoring. The results highlight the system’s capability to model user interaction patterns and predict resource utilization effectively.

Dispensing Activity Analysis

Fig. 4 illustrates the variation in food dispensing activity across different times of the day for multiple days of the week. The results indicate a clear temporal pattern, with peak dispensing observed during early morning (approximately 6:00–10:00) and evening hours (approximately 17:00–21:00). These peaks correspond to typical stray animal feeding cycles in urban environments.

A noticeable dip in activity is observed during midday hours, indicating reduced interaction during this period. Additionally, weekday trends show relatively higher and more consistent usage compared to weekends, suggesting behavioral dependence on human activity patterns. The consistency across multiple days validates the reliability of the system in capturing real-world feeding demand patterns.

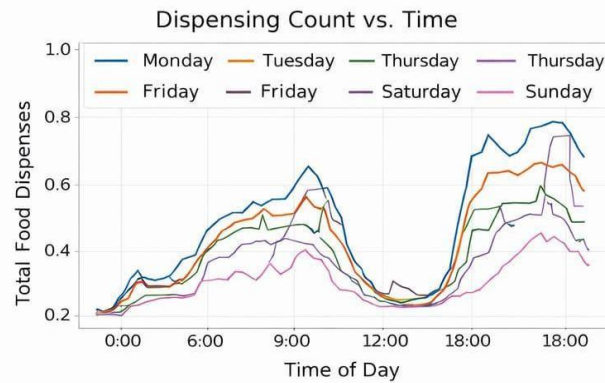


Fig. 4. Dispense Count vs. Time graph

Stock Level Prediction and Refill Optimization

Fig. 5 presents the predicted food stock levels over a future time horizon using a regression-based model. The results demonstrate a gradual and near-linear decline in stock levels, reflecting consistent consumption behavior derived from dispensing data.

The shaded region represents prediction uncertainty, while the dashed line indicates the predefined refill threshold. It is observed that the predicted stock level intersects the threshold at approximately day 9, indicating the optimal time for replenishment.

This predictive capability enables proactive maintenance and refill scheduling, reducing the risk of system downtime and ensuring uninterrupted food availability. The results validate the effectiveness of integrating data-driven forecasting into IoT-based vending infrastructure.

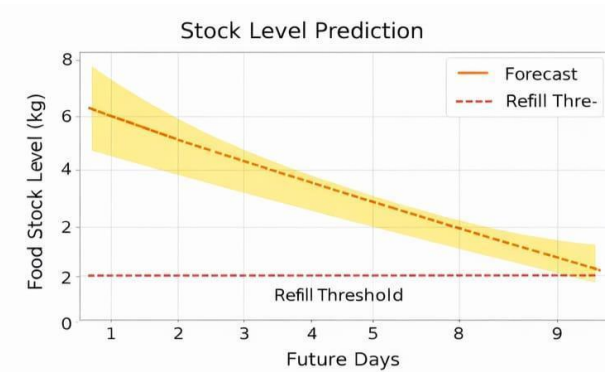


Fig. 5. Food Stock level Prediction graph.

Conclusion

This paper presented Treatmate, an IoT-enabled public dog food vending machine integrating secure transaction-based dispensing, plastic-bottle recycling activation, camera-assisted material verification, and real-time load monitoring. The system successfully demonstrates reliable embedded control using ESP32, dual-motor actuation for calibrated portion release, and cloud-based backend validation through

encrypted communication protocols. The integration of a camera-assisted bottle classifier extends the system's functionality beyond animal welfare by incorporating environmental sustainability through incentivized recycling. All operational events, including transactions, bottle insertions, dispensing quantities, image inference outcomes, and weight measurements, are centrally logged within a cloud database.

A dedicated data-management and analytics layer enables advanced analysis of feeding trends and recycling participation. By applying time-series modeling and consumption-pattern analysis, the system correlates food dispensed and recycling metrics with regional stray-dog demand, transforming operational data into actionable intelligence. Treatmate thus evolves from a standalone vending mechanism into a scalable, data-driven smart infrastructure unit capable of supporting urban animal-welfare initiatives, sustainability programs, and predictive resource optimization. The modular architecture further enables future integration of more robust vision models, automated refill prediction, and multi-location centralized deployment within smart-city ecosystems.

References

1. W. Alam, F. Sultana, J. B. Saba, and A. C. Kofi, "IoT Based Smart Vending Machine for Bangladesh," *2019 IEEE International Conference on Robotics, Automation, Artificial-Intelligence and Internet-of-Things (RAAICON)*, Dhaka, Bangladesh, 2019, pp. 73–76, doi: 10.1109/RAAICON48939.2019.36.
2. S. Tegeltija, B. Tejić, I. Šenk, L. Tarjan, and G. Ostojić, "Universal IoT Vending Machine Management Platform," *2020 19th International Symposium INFOTEH-JAHORINA (INFOTEH)*, East Sarajevo, Bosnia and Herzegovina, 2020, pp. 1–5, doi: 10.1109/INFOTEH48170.2020.9066324.
3. R. Ming and C. Zhao, "Design and Development of Smart Snack Vending Machine," *2022 International Conference on Computing, Robotics and System Sciences (ICRSS)*, Macau, China, 2022, pp. 100–103, doi: 10.1109/ICRSS57469.2022.00030.
4. B. Balakrishnan, P. Salunkhe, S. Satpute, C. Patil, and S. Phanse, "Multisense Vending Machine with Inclusive Multimodal Interaction and Digital Payments," *2025 2nd International Conference on Integration of Computational Intelligent System (ICICIS)*, Lohegaon, India, 2025, pp. 1–4, doi: 10.1109/ICICIS65613.2025.11371252.
5. K. Rambabu et al., "Automated Canine Food Vending Machine Using YOLOv5 and Arduino," *2024 10th International Conference on Communication and Signal Processing (ICCS)*, Melmaruvathur, India, 2024, pp. 411–416, doi: 10.1109/ICCS60870.2024.10543470.
6. J. Qian, C. Liu, Y. Ai, G. Zhao, and X. Qian, "Enhancing Automated Vending Machine Product Recognition Through Depth-Guided Regression Refinement," *IEEE Transactions on Industrial Informatics*, vol. 21, no. 6, pp. 4565–4575, June 2025, doi: 10.1109/TII.2025.3545046.
7. T. Yokouchi, "Today and Tomorrow of Vending Machine and Its Services in Japan," *2010 7th International Conference on Service Systems and Service Management*, Tokyo, Japan, 2010, pp. 1–5, doi: 10.1109/ICSSSM.2010.5530240.
8. W. G. P. Dumpayan, M. L. M. De Mesa, N. D. F. Yucor, E. T. Gabion, J. D. Reynoso, and G. R. M. Geslani, "Two-Way Powered Microcontroller-Based Plastic Bottles 'Drop-and-Tap' Reverse Vending Machine with Stored Value System Using Radio Frequency Identification (RFID) Scanner Technology," *2017 IEEE 9th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM)*, Manila, Philippines, 2017, pp. 1–8, doi: 10.1109/HNICEM.2017.8269433.
9. R. Thamizhamuthu, R. K. Raja, and S. Mishra, "A Controlled Gesture Smart Vending Machine Using AI Techniques," *2025 International Conference on Innovative Trends in Information Technology (ICITIT)*, Kottayam, India, 2025, pp. 1–7, doi: 10.1109/ICITIT64777.2025.11041580.
10. S. Sambhi and P. Dahiya, "Reverse Vending Machine for Managing Plastic Waste," *International Journal of System Assurance Engineering and Management*, vol. 11, no. 3, pp. 635–640, June 2020, doi: 10.1007/s13198-020-00967-y.
11. A. Yarlagadda, S. C. Teja, P. S. Teja, and N. Suresh, "Collection of Plastic Bottles by Reverse Vending Machine Using Object Detection Technique," *Materials Today: Proceedings*, vol. 80, pp. 1995–1999, 2023, doi: 10.1016/j.matpr.2021.06.037.
12. G. A. Pamungkas and A. G. Persada, "IoT-Based Reverse Vending Machine Using MobileNet SSD for Object Detection and Reward Mechanism," *Journal of Informatics and Communication Systems*, 2025.
13. F. Al Mahmud and N. Hasan, "QR Code-Based Rewarding Reverse Vending Machine for Plastic and Metal Bottles," *IEEE Computer Society Bangladesh Symposium*, 2024.
14. Y. Cao, Y. Ikenoya, T. Kawaguchi, S. Hashimoto, and T. Morino, "A Real-Time Application for the Analysis of Multi-Purpose Vending Machines with Machine Learning," *Sensors*, vol. 23, no. 4, 2023, doi: 10.3390/s23041935.
15. S. Henriques, S. Lewis, and G. Kotian, "An IoT-Based Vending Machine Using Blockchain for Enhanced Security," *Journal of ISMAC*, vol. 4, no. 3, pp. 153–164, 2022, doi: 10.36548/jismac.2022.3.002.
16. M. V. Gaddipati, K. G., and R. K. Megalingam, "FPGA-Based Reverse Vending Plastic Recycling Machine," *2024 4th Asian Conference on Innovation in Technology (ASIANCON)*, 2024, doi: 10.1109/ASIANCON62057.2024.10837894.