AI-Accelerated Raspberry Pi 5 Smart Recycling Bin for Real-Time Waste Classification

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1. Background

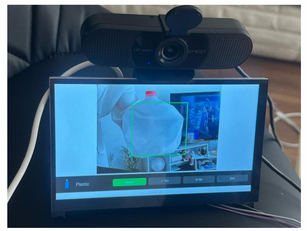
Only about 25% of material placed in U.S. recycling streams is actually recyclable; the rest is contamination that costs facilities hundreds of millions of dollars each year and sends usable resources to landfills.
Research Question: Can an edge-AI recycling bin, built around a Raspberry Pi 5 and Hailo accelerator, classify common waste items in ≤ 1s with ≥ 80% accuracy in typical indoor lighting?

2. System Architecture

Edge AI: Raspberry Pi 5 paired with a Hailo AI Hat for on-device inference
Vision Input: Camera module mounted above the display captures model input
User Interface: 7" touchscreen displays live camera feed with bounding box and class labels
Sorting Bins: Five separate bins for metal, plastic, glass, paper, and biodegradable waste
LED Feedback: WS2812 LED ring around each bin lights up representing the detected category

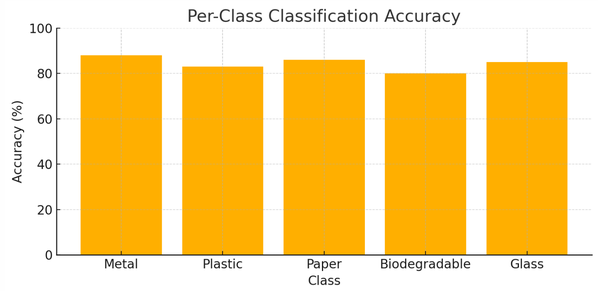
3. Methodology

Dataset: 13k images total (10k train / 2k eval / 1k test) across six classes: metal, plastic, paper, biodegradable, glass
Model: Custom YOLOv5s fine-tuned for the dataset and trained 120 epochs
Optimization: Converted weights to ONNX and compiled for Hailo AI hardware
Evaluation: 50 physical items (10 per class), three trials each



4. Results

Accuracy: 84% overall (126/150), per class – metal 90%, plastic 88%, paper 85%, glass 83%, biodegradable 78%
Inference Speed: 70 ms with Hailo AI; 310 ms CPU-only
Power Draw: 8 W peak, 6.5 W average, 3.5 W idle



5. Discussion

Our edge-AI bin achieved an overall accuracy of 84% with 310 ms inference on the Pi 5 alone, and just 70 ms with Hailo, demonstrating that low-cost hardware can support real-time waste classification. However, the results also reveal key limitations: transparent plastics and glass items are often confused, and biodegradable items can be missed entirely. Paper and plastic also share textures and shapes that cause ambiguity. These findings highlight the importance of consistent lighting and background for reliable inference. Overall, the results confirm the bin's viability while revealing what to focus on in future improvements.

6. Future Work & Impact

Future efforts could focus on campus deployment to gather real-world data, adding a servo-driven diverter for automated sorting, and evaluating a battery-powered design for portable use. Adding improvements to the camera, such as adaptive exposure and background isolation, would improve robustness under varied lighting. Logging data on a dashboard could highlight error patterns and guide further model tuning. At scale, the project could drive a 20-30% reduction in household recycling contamination, saving millions in processing costs and keeping more material out of landfills.

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