Applying Machine Learning in Waste Identification and Classification for Delta Robot Control

Tran Gia Bao | Advisor: M.Sc. Vo Minh Thanh
School of Electrical Engineering
International University, Vietnam National University-HCM City

Abstract:

Vietnam generates ~60,000 tonnes of solid waste daily, yet sorting remains manual and hazardous. This thesis proposes a low-cost automated system integrating: (1) YOLOv8n deep learning for real-time detection of plastic, metal, and paper; (2) NVIDIA Jetson Nano 4GB with TensorRT FP16 optimization; and (3) a 3-axis Delta robot with vacuum gripper for autonomous pick-and-place. The system achieves mAP@0.5 = 0.91, 8 FPS inference, 2-3 mm repeatability at ~$300 total cost -- 30-100x cheaper than commercial alternatives ($50k-$500k).

Introduction

Background:
Vietnam produces 60,000+ tonnes/day of waste; recycling rates remain critically low.
Three core problems: (1) Inconsistent sorting policies across regions; (2) Inadequate processing infrastructure; (3) Low public awareness.

Problem:
Manual sorting is slow, error-prone and exposes workers to health hazards.
No affordable automated solution for educational institutions or SMEs.

Objective:
Design a vision-guided robotic sorting prototype achieving:
mAP@0.5 >= 0.85 | >= 5 FPS | <= 5 mm repeatability | Cost < $1,000

Scope:
Lab-scale: 200x150 mm workspace, 3 classes, single-object workflow.
Foundation for scalable recycling automation in developing countries.

Methodology

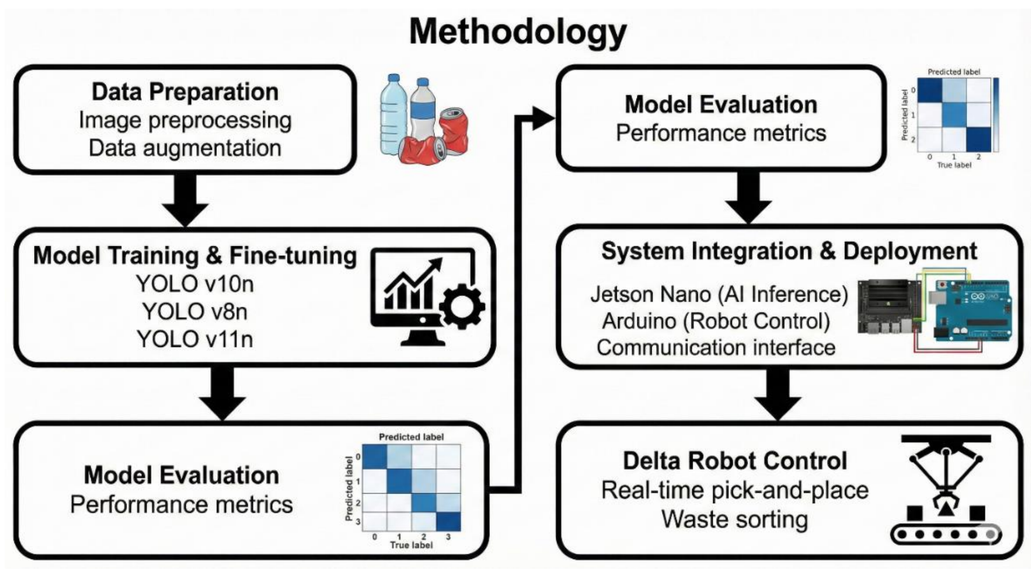


***Figure 5.1**: System Architecture and End-to-End Processing Pipeline*

Dataset:
1,705 images (1,484 RoboFlow conveyor-belt + 221 lab PS3 Eye camera)
3 classes: Plastic, Metal, Paper | Split: 1,194 train / 256 val / 255 test

Model - YOLOv8n (Transfer Learning):
Phase 1: train on RoboFlow; Phase 2: fine-tune on combined dataset
Augmentation: rotation, flip, brightness, mosaic
Hyperparams: batch=32, cosine LR (0.01->0.0001), 100 epochs

Deployment Pipeline:
PyTorch -> ONNX -> TensorRT FP16 on Jetson Nano (JetPack 4.6.4)
Resolution: 480x480 | Model size: ~8 MB | GPU RAM: 1.2 GB / 4 GB

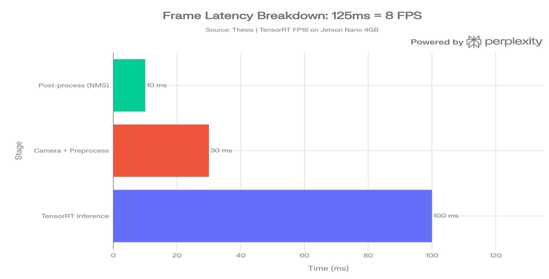
Robot Integration:
3-axis Delta + vacuum gripper + limit-switch homing
Jetson Nano -> USB Serial -> Arduino -> NEMA23 steppers
IK converts detected centroid (pixels) -> motor step positions

***Figure 5.3**: Examples from the laboratory dataset captured with the PS3 Eye camera.*

Result

Model Performance (YOLOv8n on Test Set):
Plastic : P=0.91 R=0.88 F1=0.89 mAP=0.89
Metal : P=0.94 R=0.89 F1=0.91 mAP=0.92
Paper : P=0.96 R=0.94 F1=0.95 mAP=0.94
Overall : P=0.94 R=0.90 F1=0.92 mAP=0.91 [TARGET: 0.85 - EXCEEDED]

System Performance:
Inference: 8 FPS / 125ms per frame [TARGET: >=5 FPS - MET]
Repeatability: 2-3 mm [TARGET: <=5 mm - EXCEEDED]
Power: ~19 W [TARGET: <=20 W - MET]
Hardware cost: ~$300 vs $50k-$500k commercial [30-100x saving]



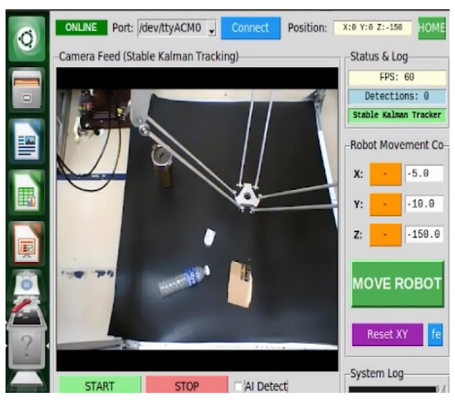


***Figure 6.14:** GUI Control Panel (Zoomed) Close-up of manual control section showing coordinate inputs and function buttons.*

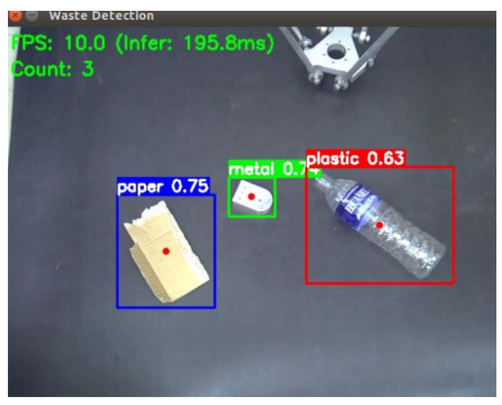


***Figure 6.11**: Overall System Detection Representative detection of one object per category (plastic, metal, paper) showing complete system functionality.*

Conclusion

Achievements:
All design specifications met or exceeded -- complete working prototype: embedded AI waste sorting system using Jetson Nano.

Key Contributions:
(1) YOLOv8n + TensorRT FP16: optimal stack for JetPack 4.6.4 (Python 3.6)
(2) Two-phase transfer learning: 0.91 mAP with only 1,705 images
(3) Mechanical redesign (M10->M6 joints + springs): 8mm -> 2-3mm accuracy
(4) Full pipeline: vision -> inference -> IK -> robot control ($300 BOM)

Limitations & Future Work:
Expand to 5-6 waste classes; conveyor-speed tracking; formal hand-eye calibration; IoT monitoring; deploy at real Vietnamese recycling facility.

Reference

[1] Redmon et al. YOLO: Unified Real-Time Object Detection. CVPR 2016.
[2] Ultralytics. YOLOv8 Documentation. 2023. ultralytics.com
[3] NVIDIA. JetPack SDK 4.6 and TensorRT Developer Guide. 2022.
[4] Zhou et al. Garbage Detection System Based on YOLOv8. 2023.
[5] Ardias et al. Smart Waste Classification with YOLOv5 on Jetson Nano. 2022.
[6] World Bank. Vietnam Waste Management Assessment. 2021.
[7] Siciliano et al. Robotics: Modelling, Planning and Control. Springer, 2008.
[8] Roboflow. Open-Source Conveyor Belt Waste Dataset (CC-BY 4.0). 2023.

Hochiminh City, March 2026