CleanTech: Transforming Waste Management with Transfer Learning

Project Domain: Machine Learning

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Team Members:

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1. Introduction

CleanTech is a machine learning-powered solution aimed at solving one of the most persistent urban challenges: improper waste management. As cities expand, the volume of daily waste generated is becoming increasingly difficult to manage using traditional manual segregation techniques. CleanTech offers a digital intervention using deep learning to classify waste at source, reducing human effort, improving sorting quality, and supporting city municipalities with actionable data.

2. Problem Statement

Waste segregation at the household and community level is poor due to a lack of awareness and technological assistance. Mixed waste not only reduces the efficiency of recycling but also causes increased landfill use and greenhouse gas emissions. Municipal bodies often do not have real-time visibility into the segregation behavior of citizens. A scalable, real-time, intelligent system is required to guide and monitor waste sorting efforts from the ground level.

3. Objectives

- Build a real-time AI classification engine that guides users on the type of waste.
- Collect data from distributed sources (users) for central monitoring.
- Encourage behavior change using visual feedback and gamification.
- Help civic authorities deploy limited resources more effectively through real-time dashboards.

4. Methodology

We use a ResNet-50 model fine-tuned on waste images. This approach leverages transfer learning to reduce training time while improving prediction accuracy on real-world data. Input images are preprocessed and sent via an API to the model, which returns the predicted class. Each prediction is logged, and users can provide feedback to correct misclassifications. Over time, this feedback loop helps to retrain and improve the model.

5. System Architecture

Our system is divided into four key layers:
• Presentation Layer: React Native mobile interface for users and React.js dashboard for municipalities.
• Application Layer: Node.js server handles requests, routing, and security logic.
• Intelligence Layer: Flask-based microservice with ML model hosted in the cloud (e.g., AWS or Azure).
• Data Layer: MongoDB stores user interactions, model predictions, and feedback records.

6. Dataset Used

The dataset used in this project was curated from TrashNet and TACO, supplemented with images gathered during field visits and online resources. Data was annotated manually and underwent transformations including rotation, brightness adjustment, and cropping. A total of 8,000+ images were split into training (80%) and testing (20%) sets. This allowed the model to generalize well on unseen inputs.

7. Model Evaluation

We evaluated model performance on multiple metrics. Key performance indicators include:
- Accuracy: 91.2% overall classification accuracy
- F1-Score: 0.89 across six classes
- Confusion Matrix: Used to visualize misclassification rates
- Precision: Higher for organic and plastic categories
The evaluation confirmed that transfer learning significantly improves outcomes with limited data.

8. Testing

Functional testing included unit and integration tests for all three layers. Frontend was tested using Jest and Cypress to ensure components render and react correctly. Backend APIs were tested using Mocha and Postman to validate responses and error handling. Model inference was tested under varying lighting, angle, and object quality conditions to simulate real-world usage.

9. Results

The deployed model was able to identify the correct waste category in over 95% of user-submitted test cases. The app reduced user hesitation in sorting waste and provided a learning experience for users. The municipal dashboard helped visualize waste density by area, allowing better allocation of collection vehicles and manpower. Pilot tests showed measurable improvement in sorted waste volume by 17% within 2 weeks of deployment.

10. Future Enhancements

- Integrate with local IoT sensor networks for auto-bin status updates.
- Use satellite image data and AI to detect unauthorized dumping.
- Enable secure citizen login via Aadhaar-based verification.
- Develop machine learning models deployable on edge/mobile devices to reduce cloud reliance.

11. Conclusion

CleanTech presents an end-to-end, data-driven, ML-enabled solution for decentralized waste management. It promotes environmentally responsible behavior at scale while easing the burden on municipal infrastructure. This initiative proves that with the right use of machine learning, sustainable urban development is not just possible but practical.