Material Stream Identification System

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1. Introduction

This project implements Material Stream Identification (MSI) system for post-consumer waste sorting. The system follows a classical machine learning pipeline consisting of data augmentation, feature extraction, classifier training, evaluation, and real-time deployment. The goal is to classify waste images into six material classes and reject uncertain inputs as Unknown.

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2. Dataset and Data Augmentation

The provided dataset contains images for six material classes: **glass, paper, cardboard, plastic, metal, and trash.**

To improve generalization and class balance, **data augmentation** was applied to increase the dataset size to **500 images** per class. Each original image generates additional samples using:

- Horizontal flipping: used to teach model to ignore the directionality of the objects.
- Rotation by ±15° : used to teach model to ignore the rotation of the objects.

This results in a minimum dataset increase of over 200%, improving robustness against orientation and viewpoint variations.

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3. Feature Extraction

Each image is converted into a fixed length **1D numerical feature vector**, as required.

3.1 Preprocessing

ensures that all images have the same size and format

- Images are resized to **128 × 64** pixels as a standard size.
- Color images are converted to grayscale for texture analysis.

3.2 HOG Features

Histogram of Oriented Gradients (HOG) is used to extract **shape and edge information** , which is effective for distinguishing structured objects such as bottles, cans, and cardboard. It focus on important object details while reducing noise.

3.3 Color Features

To capture color distribution and object parts (e.g., labels or caps), the image is vertically divided into three regions (top, middle, bottom). For each part, color histograms are extracted in the **HSV color space**. Only the **Hue and Saturation** channels are used because they are more stable under lighting changes. The histograms are **normalized** to make the features scale-independent.

3.4 Final Feature Vector

The final feature vector is created by combining:

- HOG features (shape and texture)
- HSV color histograms (color information)

This produces a representation suitable for classical classifiers.

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4. Models

4.1 Support Vector Machine (SVM)

The Support Vector Machine (SVM) classifier is trained using the extracted features. Works well with high-dimensional feature vectors. Provides probability estimates for predictions. effective at finding clear boundaries between different material classes, And its accuracy according to the test data is nearly 87%.

4.2 k-Nearest Neighbors (k-NN)

The k-Nearest Neighbors classifier is used as a comparison model.

Key properties:

- Uses k = 5 nearest neighbors
- Applies distance-based weighting

k-NN is slower during prediction and performs worse with high-dimensional data, it accuracy is nearly 74%

so mostly the SVM model was better to use on the test data than the KNN one

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5. Handling the "Unknown" Class

The system detect inputs that do not belong to any known material class or are unclear.

This is done using **confidence-based rejection**:

- **SVM**: If the highest prediction probability is below a fixed threshold, the image is labeled as Unknown.
- **k-NN**: If the average distance to the nearest neighbors is too large, the image is labeled as Unknown.

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6. Model Evaluation

The dataset is split into: 80% training data and 20% testing data. Accuracy is used to evaluate performance.
The SVM model achieves higher accuracy than k-NN and performs better on visually similar materials. Therefore, the SVM model is selected as the final system model.

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7. Real-Time System Deployment

The trained model is integrated into a **real-time camera application** using OpenCV.

Steps:

- Capture live video frames
- Crop the center region of the frame
- Extract features from the image

- Predict the material class
- Display the result and confidence on screen