

GitHub Repo Link:

<https://github.com/sohyla-said/Material-Stream-Identification-System>

Comprehensive Technical Report:

Feature Extraction – CNN(ResNet-50):

- **Motivation:**
 - CNNs automatically learn multi-level features, overcoming limitations of handcrafted descriptors like HOG, LBP or color histograms.
 - Early layers detect edges/corners. Middle layers detect textures. Deep layers detect object parts and patterns.
- **Why ResNet-50:**
 - It is deeper (**50 layer**), so it learns more abstract features.
 - It captures fine material cues (metal shine, glass reflections, plastic texture).
 - It has residual connections, making training more stable.
 - It is pretrained on **ImageNet**, a massive dataset of 1.2M images.
 - Outputs **2048-dimensional** feature vectors suitable for SVM/KNN.
- **Implementation:**
 - Images resized and normalized according to ResNet-50 requirements.
 - Feature vectors extracted from the last average pooling layer (before fully connected layers).
 - Saved as NumPy arrays for downstream classification.

Data Augmentation:

- Techniques used: **rotation** ($\pm 10^\circ$), **horizontal flip** and **brightness/contrast jitter**.
- Purpose: increase dataset size, improve generalization, handle variations in lighting and orientation.
- Augmentation increased class samples by $\geq 30\%$.

Classifier Implementation:

- **Support Vector Machine (SVM) classifier:**
 - Implemented an SVM classifier using scikit-learn's **SVC** with RBF kernel.

- Input to the SVM is the 2048-dimensional feature vector extracted from images using a pretrained ResNet-50 model.
- Hyperparameters such as **C** and **gamma** were tuned via grid search with stratified 5-fold cross-validation.
- Final model uses parameters:
 - **kernel='rbf', C=5, gamma='auto'.**
- A confidence-based rejection mechanism was added:
 - Predictions with confidence (maximum class probability) below an optimized threshold are assigned the label "**unknown**" (**ID 6**) to avoid misclassification of uncertain samples.
- **k-Nearest Neighbors (k-NN) Classifier:**
 - Implemented a k-NN classifier with distance-weighted voting (**weights='distance'**), using the Euclidean distance metric.
 - Hyperparameters such as **n_neighbors** and **distance metric** were tuned using grid search.
 - A rejection mechanism was designed based on inverse mean distance confidence:
 - Predictions with confidence below a threshold are labeled as "**unknown**" (**ID 6**).

Performance Evaluation:

- **SVM Classification Report:**

Class	Precision	Recall	F1-score	Support
cardboard	1.00	0.94	0.97	50
glass	0.88	0.90	0.89	77
metal	0.86	0.94	0.89	63
paper	0.92	0.98	0.95	90
plastic	0.91	0.86	0.89	73
trash	0.81	0.59	0.68	22
Accuracy	0.90			375

- **K-NN Classification Report**

Class	Precision	Recall	F1-score	Support
cardboard	0.94	0.92	0.93	50
glass	0.80	0.87	0.83	77
metal	0.81	0.83	0.82	63
paper	0.92	0.89	0.90	90

Class	Precision	Recall	F1-score	Support
plastic	0.90	0.84	0.87	73
trash	0.57	0.59	0.58	22
Accuracy	0.85			375

- **Architecture Comparison:**

Model	Accuracy	Train Time (s)	Inference Time (s)	Memory Efficient
SVM (RBF)	0.904	45.326	1.513	Yes
k-NN (k=3)	0.850	0.0047	0.101	No