Pattern Recognition Systems-Practice-Module 4.0 –FT

An Intelligent Garbage Classification System

Based on Machine Learning and Deep Learning

Project Final Video Presentation

Group 15th: EZABLE

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01. Introduction

1.1 Background: Sustainable, Lower-Carbon and Recycling

Global Action

Transition to Resilient and Sustainable Urban Futures. Securing a Greener Urban Future.

As such, the transition to net zero greenhouse gas emissions must occur as soon as feasibly possible. Cities can do their part by embracing a wide range of options.

--- *UN-Habitat, "WORLD CITIES REPORT 2022: Envisaging the Future of Cities"*

Make cities and human settlements inclusive, safe, resilient and sustainable.

Ensure sustainable consumption and production patterns.

--- *UN Sustainable Development Goals #11&#12*

SG Action

Charting Singapore's Low-Carbon and Climate Resilient Future.

Transformations in industry, economy and society, e.g. more renewable energy, greater energy efficiency, reducing energy consumption.

Improving energy efficiency is a key focus of our efforts to reduce emissions.

--- *Singapore, Long-Term Low-Emissions Development Strategy (LEDS)*

Peak 65Mt	Halve 33Mt	Zero Emission
2030	2050	2050-2100

1.2 Waste and Green Future for SG

Sound and reasonable waste management for low-carbon and green future.

- Inevitable requirement of urban **sustainable development**.
  - ✓ Reduce the **amount** of incineration and landfill.
  - ✓ Reduce the **carbon emission** from the source.
  - ✓ Improve the **recyclability** of garbage.
  - ✓ Promote **circular economy**.
- Fundamental way to solve the **urban waste management**.
  - ✓ **Digital transformation** of waste management.
  - ✓ Accelerate the construction of **smart cities**.
  - ✓ Alleviate the shortage of **land & human resources**.

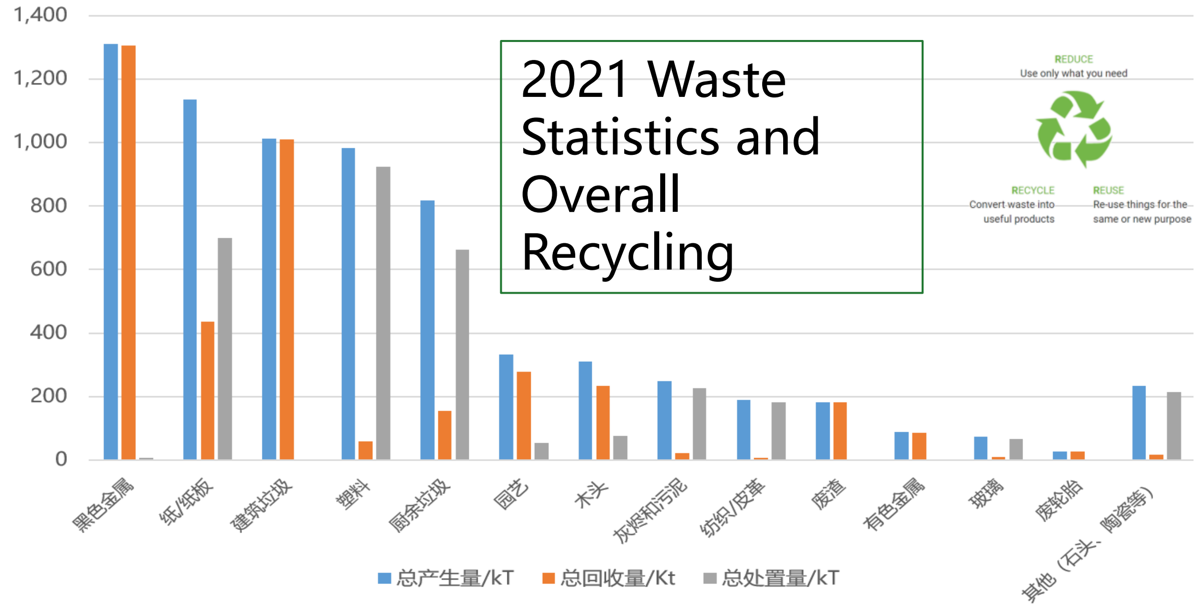
Garbage production in Singapore

6.94Mt	588Mt	723Mt
2021	2020	2020

1.3 t/year	3.7 kg/day
Per Person	Per Person

Many processes of waste treatment such as **fermentation**, **transportation**, **incineration** and **landfill** are important sources of anthropogenic greenhouse gas emissions, which also aggravates the **scarcity of land resources**. (IPCC)

1.3 Pain Point: Greater Production with Low Recovery Rate



Compared to the period before COVID-19, 2021:

- ☐ 5% less waste generated, 5% more waste disposed
- ☐ **11% lower amount of recycled**

Increase in **household waste** produced and recycled.

Reduce, Reuse, Recycle for waste minimization recycling.

More needs to be done to improve the recycling rate of **Plastic waste, Paper/Cardboard, glass, Textile/Leather** as they remains low.

Garbage Recovery Rate in Singapore

59%	52%	55%
2019	**2020**	**2021**

Aims to achieve a **70%** waste recovery rate by **2030**

- Workers have to spend much time on manual classification in bad situations.
- Unreasonable classification of valuable wastes leads to incineration or landfill.

- It is easy and often to be polluted by other wastes such as kitchen waste during transportation and transfer.
- A large number of recyclables lose their recycling value.

1.4 Team and People

LIN Zhengxi
Frontend and Backend Development

ZOU Yufan
Software Testing, Data Preprocessing

GUO Rui
Deep Learning Model Vision Algorithm

YUE Yiran
PM and Documents Potential Solutions

EZABLE =
Easy Able

- The pattern on the left represents **green and recyclable**
- The team name---***EZABLE***---represents enabling and empowering AI to the traditional industry

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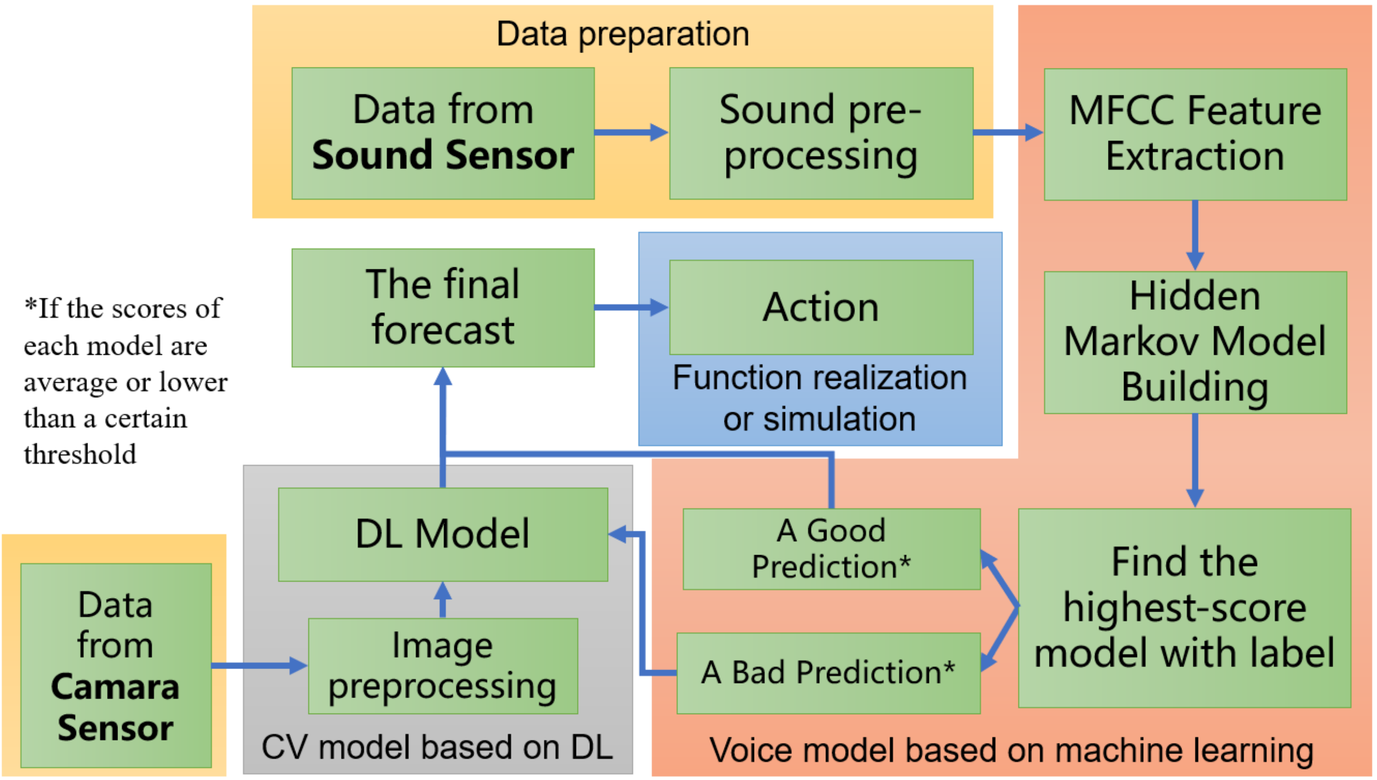
- ***EZABLE*** consists of four people.
- Capable in project development related to pattern recognition, deep learning and software engineering.
- Most of members have working, investment or entrepreneurship experiences about AI and IT field.
- Supporters of green circular economy and ECG.

1.5 Design of EZABLE

GOALS OF EZABLE

- Solve the problem of domestic waste classification from the source.
- Reduce the pressure of manual classification sorting and labor demand.

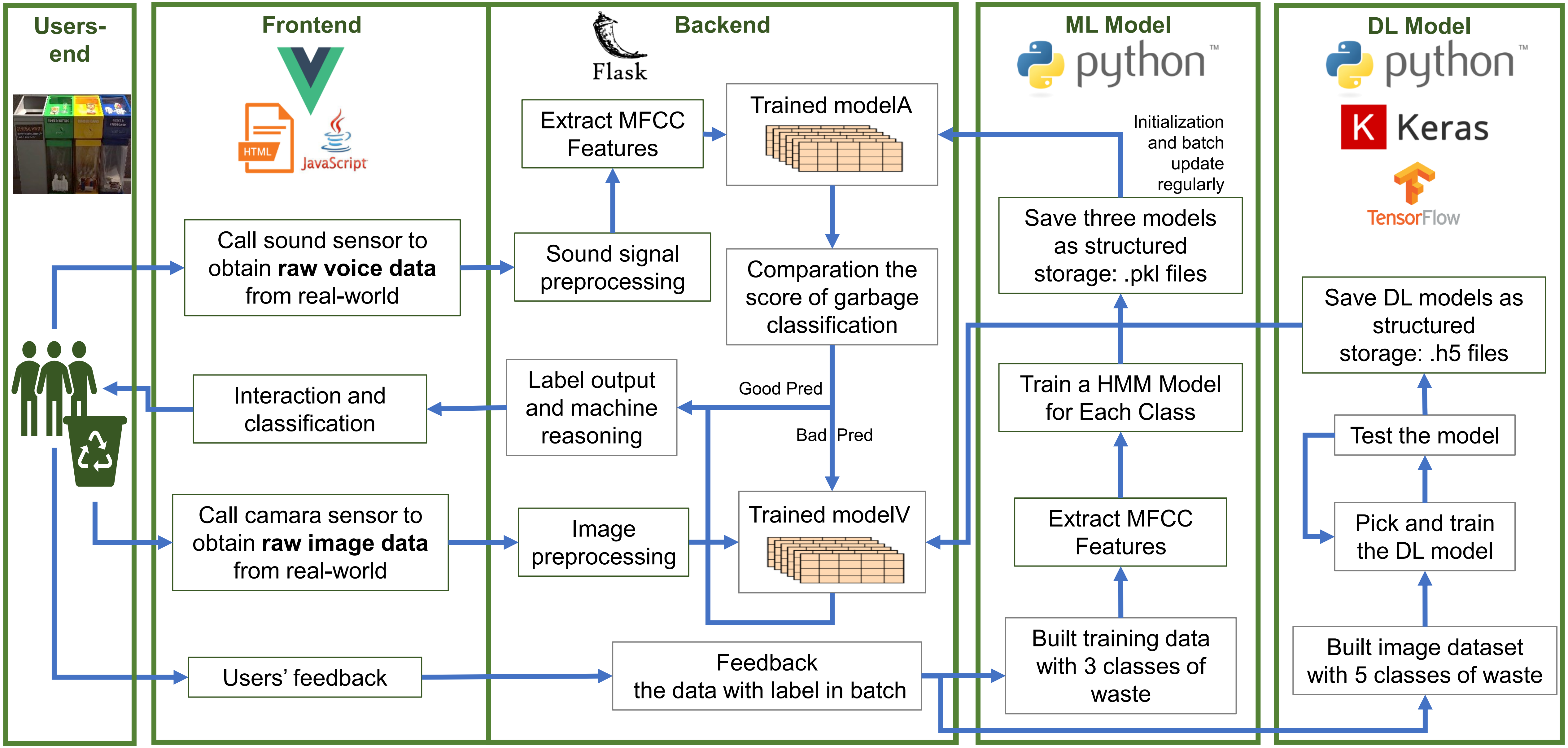
- ✓ An intelligent garbage classification and detection system based on DL and ML.
- ✓ Improving the existing garbage collection system with good compatibility.
- ✓ Embedded in street trash cans, which can also be designed as a large bin.
  - We divided the overall system into three parts, Data, Model, Software
  - The right figure shows the roadmap of system now.



02. Solution


RECYCLING
Lorem ipsum dolor sit amet, consectetuer adipiscing elit,
sed diam nonummy nibh euismod tincidunt ut laoreet
dolore magna aliquam erat volutpat.
EZABLE

2.1 Solution Implementation



2.2 Software Development: Front-end and Back-end

Development Frame

- Frontend---Vue
- Backend---Flask

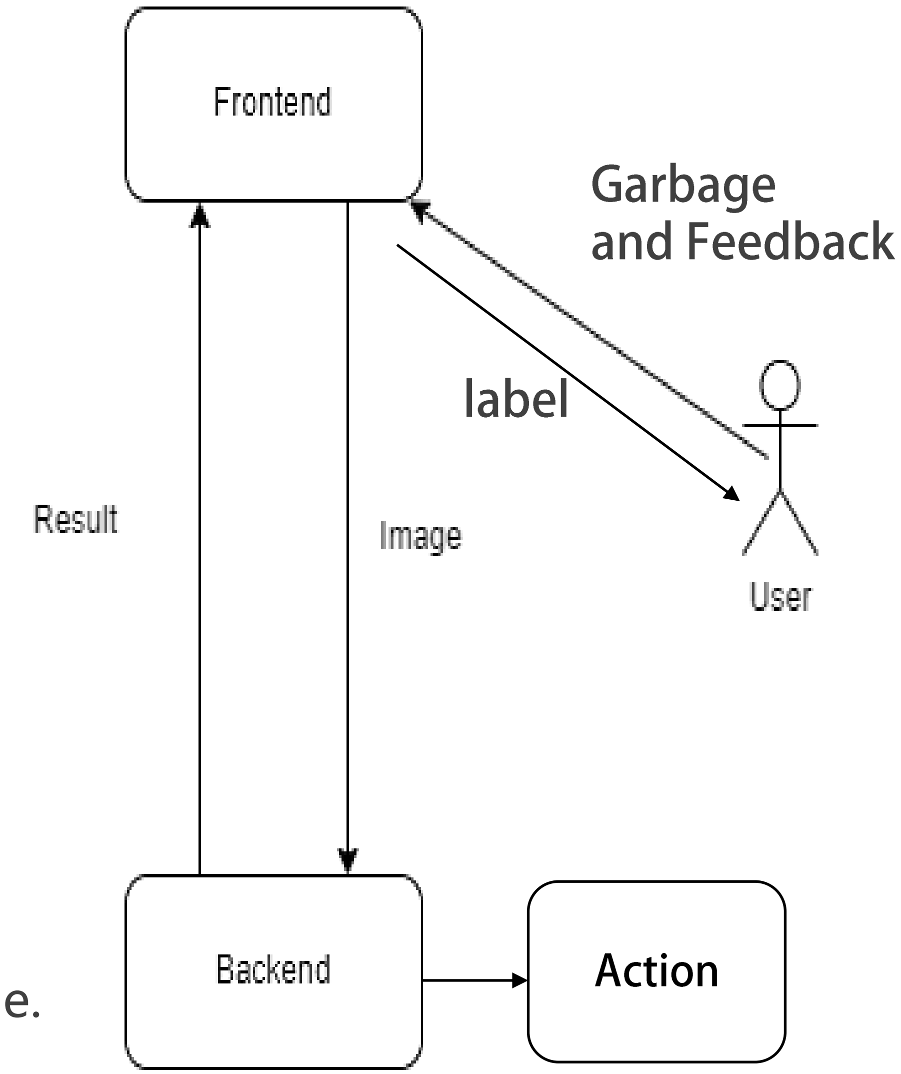
Simulation of Actual Function

The function of real world:

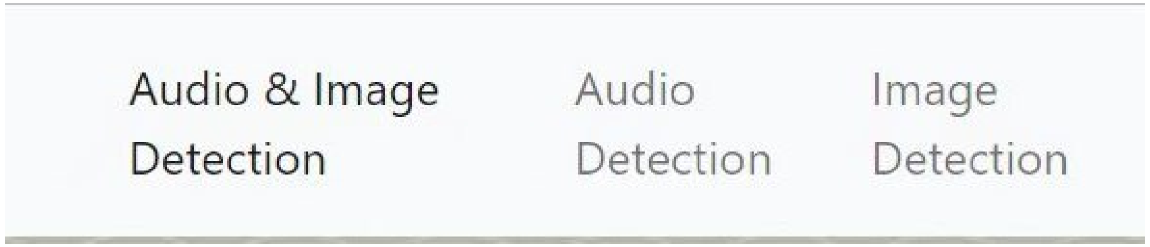
- When new garbage is thrown into the garbage can, the camera inside the can will take a photo of it.
- The model predicts which class this waste belongs, then output the label and take classification measures.

The simulation of our system:

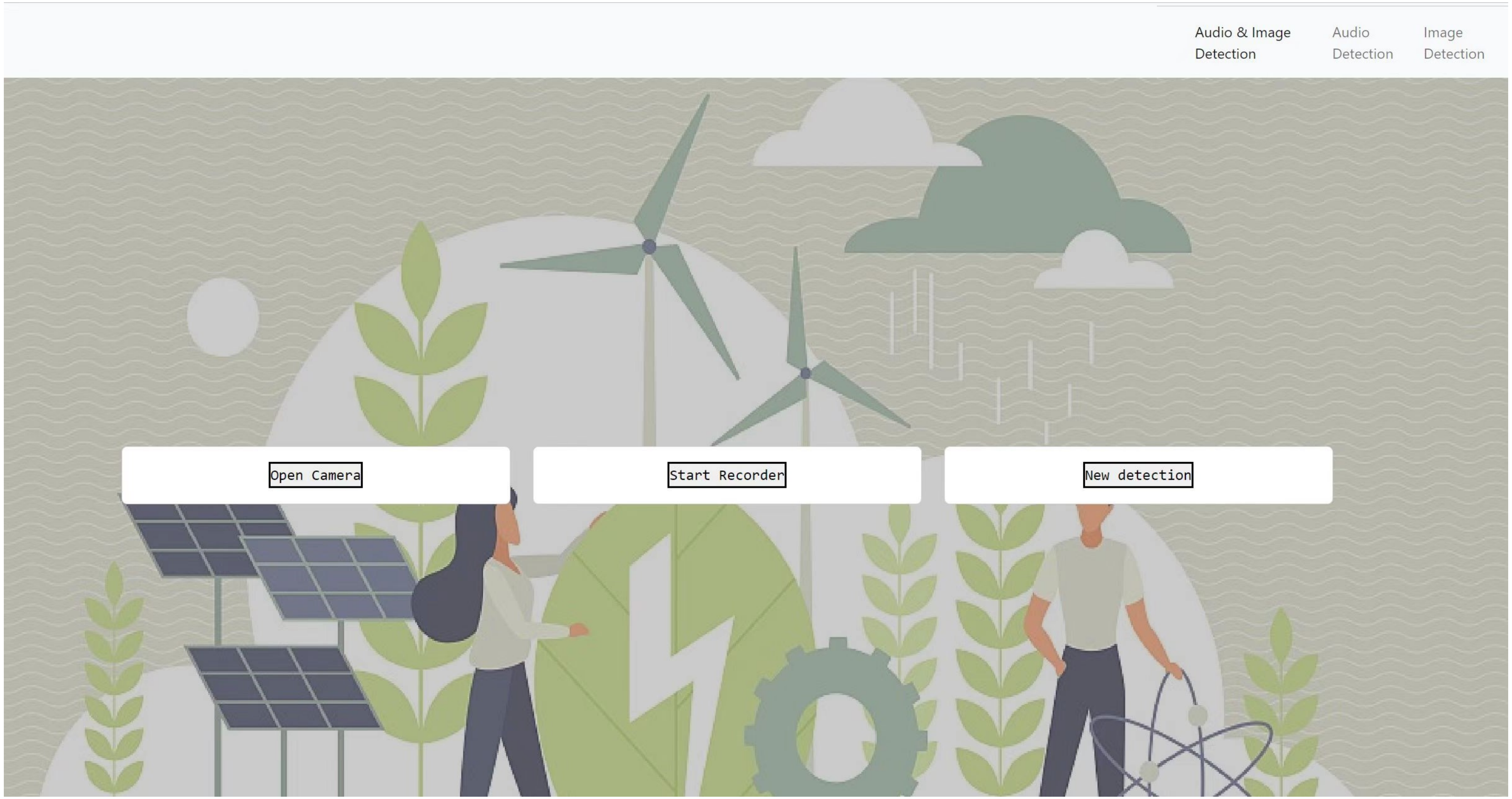
- Frontend---HC interaction. The user clicks and selects the type of garbage to be put in, and simulates the input of garbage.
- Backend---Upload test image as simulation for throw-in a garbage. Then processing the whole model as same as the real machine.



2.3 UI Design and Interaction



2.3 UI Design and Interaction



2.3 UI Design and Interaction

2.4 Data Preparation

1. Image

➢ Dataset: 5 types of garbage

224px

224px

Carton

Metal

Plastic

Glass

Other Trash

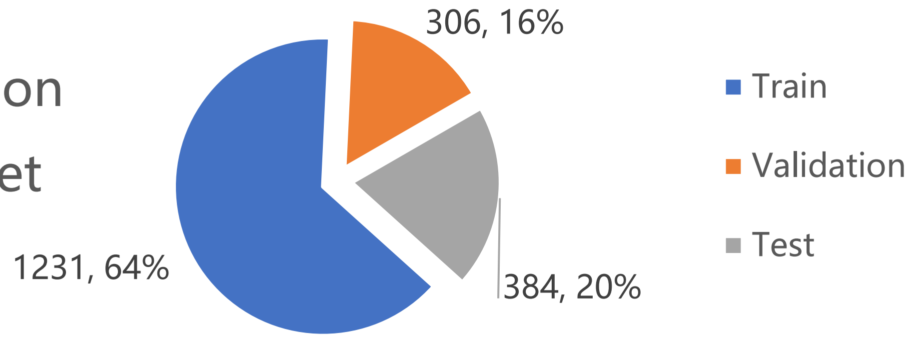
Preprocessing of Dataset for Training

1. Remove some blurry, unclear and hard to categorize to labels garbage images.

2. Re-categorize the garbage images collected above by labels. And try to have basically the same number of images per label.

3. Make all images have an aspect ratio of 1:1.

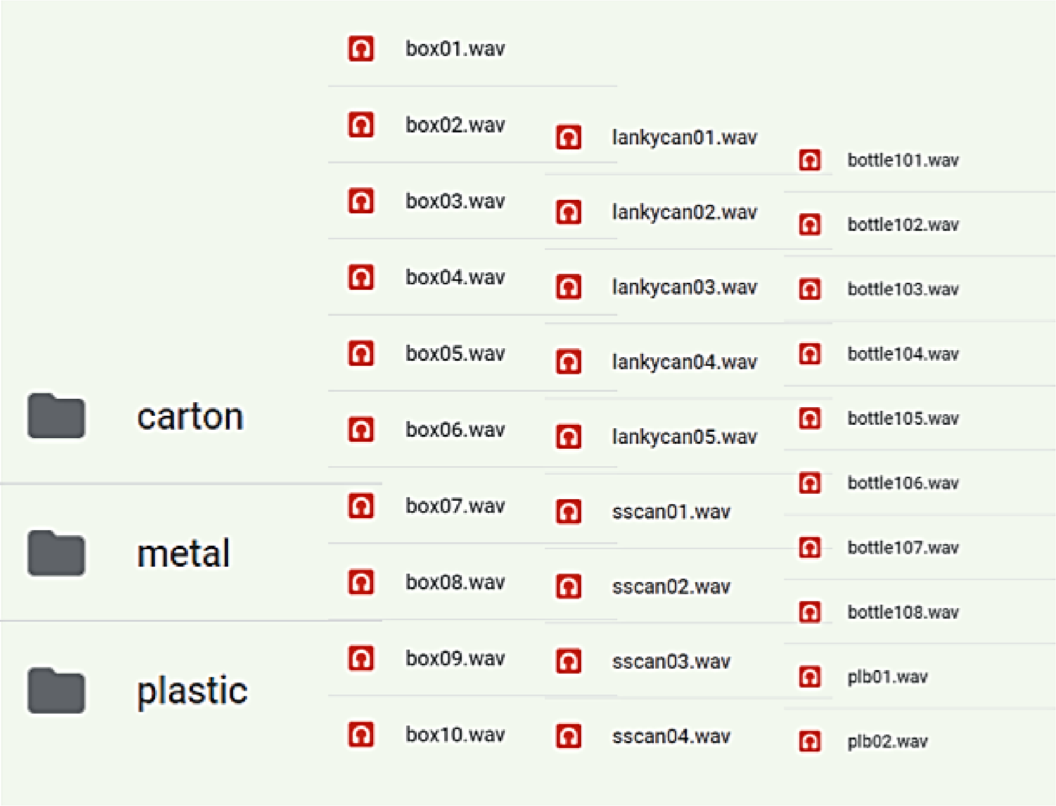
Distribution of dataset



2.4 Data Preparation

2. Voice

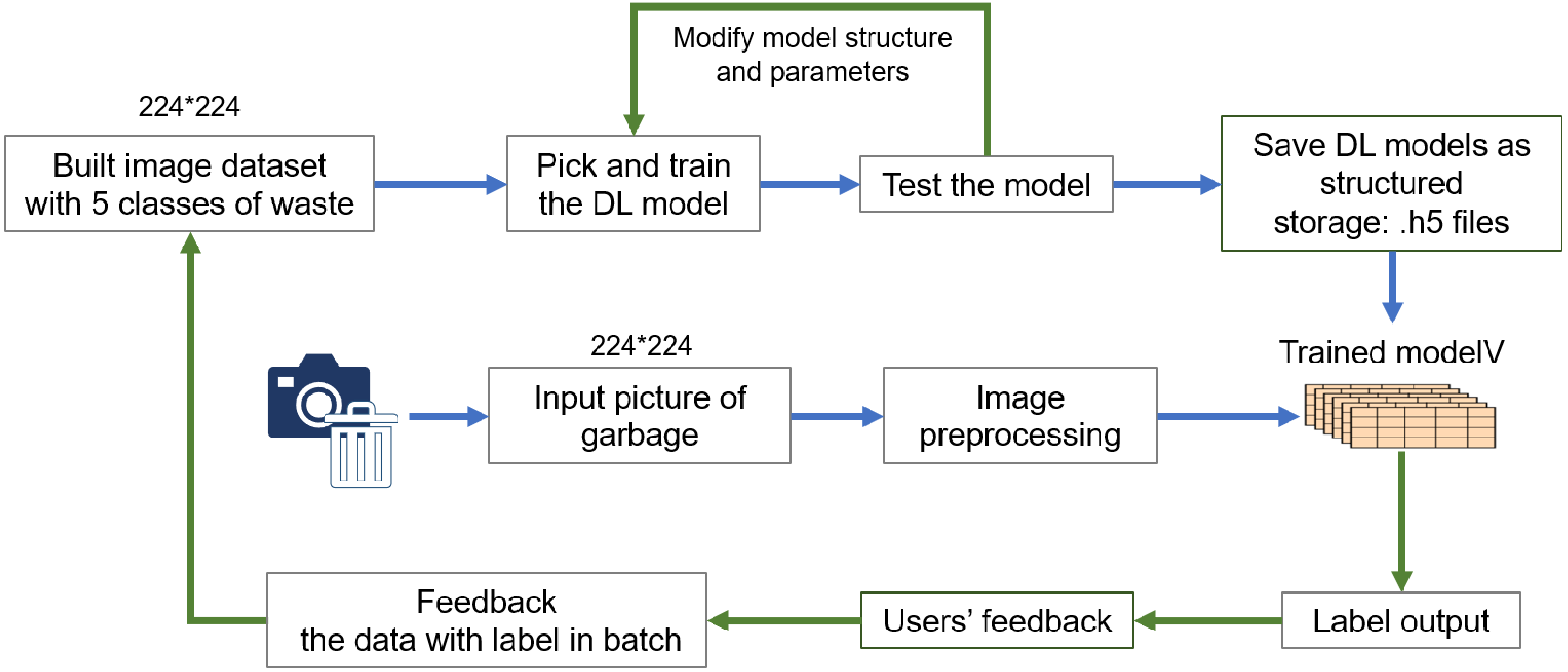
Table Details of Datasets		
Dataset Characteristics		Information
Total Number of Data		Almost 150, metal(17+), plastic(69+) and carton(62+)
Number of each kind of items	Big Plastic Bottle	16
	Middle Plastic Bottle 1	12
	Middle Plastic Bottle 2	9
	Small Plastic Bottle	14
	Plastic Cup	18
	Milk box	16
	Big Carton	21
	Small Carton	20
	Recyclable Paper	5
	Metal Can	7
	Other Metal	10
Average Size of Files		150.9 kb
Average Length of Sounds		1.32 s



Clipping → **Speed-Changing** → **Channel Integration** → **Noise Reduction**

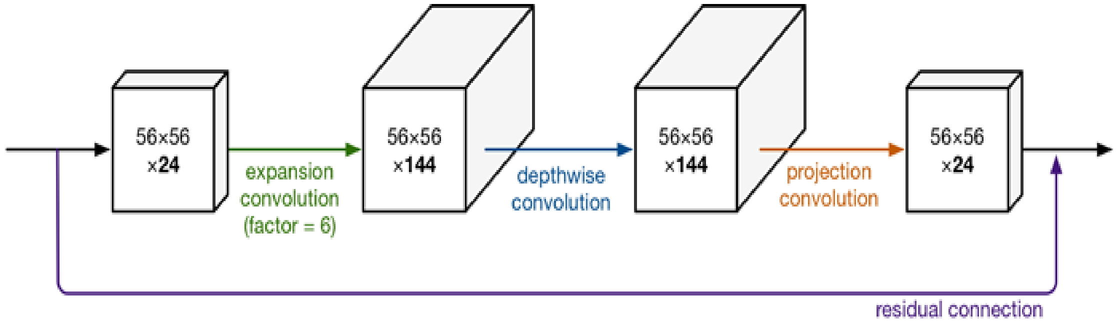
2.5 Visual Model

1. Overall Roadmap



2.5 Visual Model

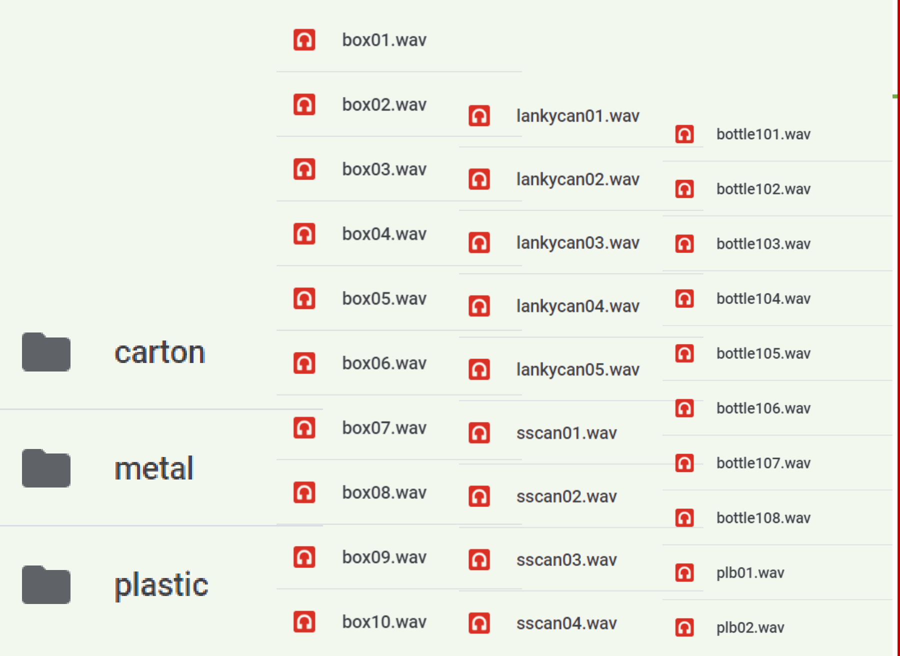
2. DL Model: MobilenetV2



Input	Operator	t	c	n	s
$224^2 \times 3$	conv2d	-	32	1	2
$112^2 \times 32$	bottleneck	1	16	1	1
$112^2 \times 16$	bottleneck	6	24	2	2
$56^2 \times 24$	bottleneck	6	32	3	2
$28^2 \times 32$	bottleneck	6	64	4	2
$14^2 \times 64$	bottleneck	6	96	3	1
$14^2 \times 96$	bottleneck	6	160	3	2
$7^2 \times 160$	bottleneck	6	320	1	1
$7^2 \times 320$	conv2d 1x1	-	1280	1	1
$7^2 \times 1280$	avgpool 7x7	-	-	1	-
$1 \times 1 \times 1280$	conv2d 1x1	-	k	-	

2.6 Acoustic Model: HMM and MFCC Feature

1. Overall Design



Training data: 3 classes different number of samples (audio clip) in each class

1. Extract MFCC Features

2. Build a HMM Model for Each Class

A set of trained HMM models (Totally 3 models for 3 classes)

3. Evaluate with 3 models and choose the model with the largest confidence score output

Recognition result

Raw sound data from real world

Data preprocessing

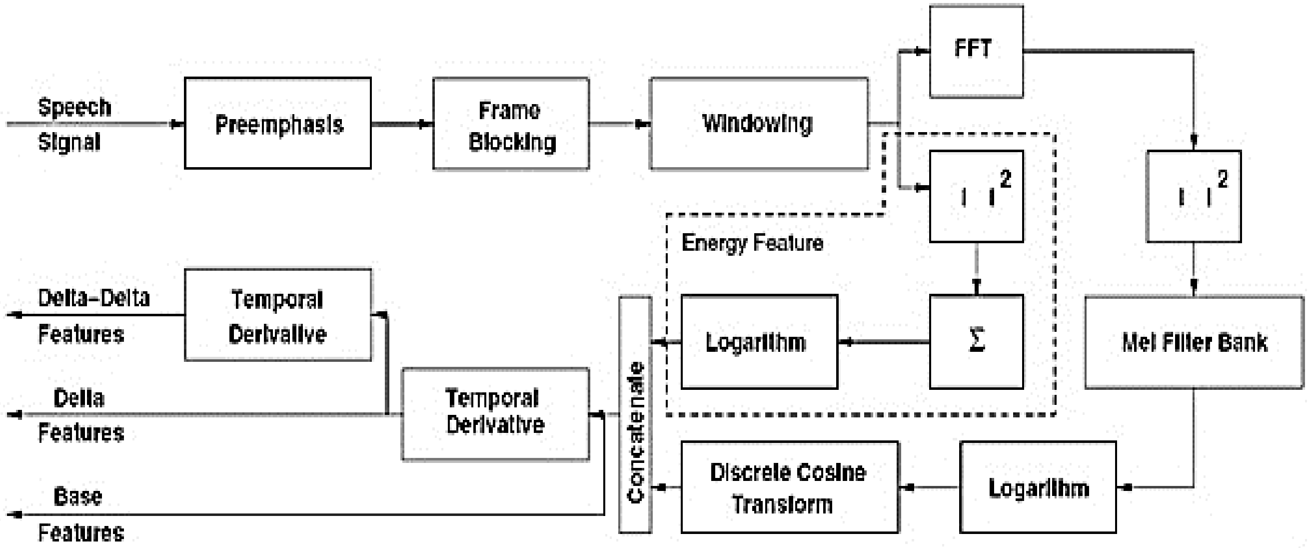
Extract MFCC Features

Action and Reasoning

2.6 Acoustic Model: HMM and MFCC Feature

2. Feature Extraction

- First, the pending signal is pre-emphasized, divided into frames, windowed and FFT (Fast Fourier Transform).
- Then, in the calculation of power spectrum, the obtained power spectrum is passed through a triangular band-pass filter, and the filtered output results are converted into logarithmic form using the relationship between Mel-scale and linear frequency.
- Finally, the MFCC coefficients are obtained by DCT transformation.




```python
#python_speech_features库提取每一帧的mfcc并计算13个特征的平均值
def mfcc_mean_features(filename):
    mfcc_mean_features = list()
    (rate,sig) = wav.read(filename)
    mfcc_feat = mfcc(sig,rate)
    #d_mfcc_feat = delta(mfcc_feat, 2)
    #logfbank生成26个特征
    #fbank_feat = logfbank(sig,rate)
    for el in mfcc_feat.transpose():
        mfcc_mean_features.append(np.mean(el))
    return mfcc_mean_features
```

2.6 Acoustic Model: HMM and MFCC Feature

3. HMM Building

- A *Hidden Markov Model* allows us to talk about both observed events and hidden events (like part-of-speech tags) that we think of as causal factors in our probabilistic model.

$Q = q_1 q_2 \ldots q_N$	a set of N **states**
$A = a_{11} \ldots a_{ij} \ldots a_{NN}$	a **transition probability matrix** A, each a_{ij} representing the probability of moving from state i to state j, s.t. $\sum_{j=1}^{N} a_{ij} = 1 \quad \forall i$
$O = o_1 o_2 \ldots o_T$	a sequence of T **observations**, each one drawn from a vocabulary $V = v_1, v_2, \ldots, v_V$
$B = b_i(o_t)$	a sequence of **observation likelihoods**, also called **emission probabilities**, each expressing the probability of an observation o_t being generated from a state i
$\pi = \pi_1, \pi_2, \ldots, \pi_N$	an **initial probability distribution** over states. π_i is the probability that the Markov chain will start in state i. Some states j may have $\pi_j = 0$, meaning that they cannot be initial states. Also, $\sum_{i=1}^{n} \pi_i = 1$

- In the acoustic model, we have selected GaussianHMM as our basic, which can be understood as a Hidden Markov Model with Gaussian Distribution. The python library *hmmlearn* has provide us a quick way to build models. We use the function *GaussianHMM* to define the class which can handle all HMM related processing and create, train and save a HMM model.

```
class hmmlearn.hmm.GaussianHMM(n_components=1, covariance_type='diag', min_covar=0.001,
startprob_prior=1.0, transmat_prior=1.0, means_prior=0, means_weight=0, covars_prior=0.01,
covars_weight=1, algorithm='viterbi', random_state=None, n_iter=10, tol=0.01, verbose=False,
params='stmc', init_params='stmc', implementation='log')
```

Hidden Markov Model with Gaussian emissions.

Variables:
- **n_features** (*int*) – Dimensionality of the Gaussian emissions.
- **monitor** (*ConvergenceMonitor*) – Monitor object used to check the convergence of EM.
- **startprob** (*array, shape (n_components,)*) – Initial state occupation distribution.
- **transmat** (*array, shape (n_components, n_components)*) – Matrix of transition probabilities between states.
- **means** (*array, shape (n_components, n_features)*) – Mean parameters for each state.
- **covars** (*array*) –

  Covariance parameters for each state.
  The shape depends on `covariance_type`:
  - (n_components,) if "spherical",
  - (n_components, n_features) if "diag",
  - (n_components, n_features, n_features) if "full",
  - (n_features, n_features) if "tied".

03. Summary

3.1 Project Scope

1. Project Schedule

- More than one month
- Three stages
- Now finish the *Part I*
- Design, build and code in progress as planning

2. Expected Deliverables

- A runnable Garbage classification system
- Datasets and whole model
- Final report and video
- Supporting documents

Gantt Chart of EZABLE---5002

Week		8th				9th				10th				11th				12th			
Days' Part		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Project Definition	Problem Definition																				
	Requirement Analysis																				
	Feasibility Analysis																				
Development	Overall Design																				
	Detailed Design																				
	Build and Code																				
Test and Finish	Integration and Unit Test																				
	Finish all Documents																				

- ➢ Each week is divided into four parts: 2+2+2+1. The last day is for F2F meeting and a short break. Other days we all will devote into the project.
- ➢ All Deliverables meet project requirements.

3.2 What Have We Gained

- We have successfully built a functioning MVP of intelligent garbage classification system. The system produces satisfactory results, and the user feedbacks are good as well. Most importantly, the system we have developed has the potential to play a role within the waste collection system by providing chances to improve the recovery rate.
- A good practice of project management too, keeping progressing throughout the project.
- A better understanding of the course content and utilize them in our projects, achieving mastery through a comprehensive study of the subject. We applied the
    - **Deep learning, neural network model (especially CNN)**
    - **Multimodal identification and model hybrid**
    - **Sensor signal processing**
    - **HMM and speech recognition**
- Our team also had a wonderful time working on this project, and along the way we have gained valuable knowledge and practical skills while achieving the prescribed objectives of this project.

3.3 Limitation

- Due to limited time, we only simulated the function of the system, and did not design the hardware system and structure. The simulation results tell us that the system is feasible.
- The recognition results rely on high-quality sound knowledge as the training dataset for the model. The datasets in this project were collected and established manually by project members, which took a lot of time and manpower.
- The acoustic model is highly depended on the certain devices. Different sensor devices may have different results. This problem is caused by different technology parameters of sound sensor. Unified sound sensor is used in EZABLE, and the recording parameters are also unified when the front end of the system calls this function.

3.4 Social Meanings: Merit lies in present and future

- Replace thousands of unnecessary servicer in the waste sorting recycling.
- Stabilize supply and demand of employment.
- Promote the transformation to high-end and advanced technology.
- Providing advanced productivity and alleviating manpower shortage.

- Cost saving, replace small companies and corresponding service personnel responsible for recyclable business to a certain extent.
- Rationalize cost input and concentrate resources on the four leading treatment manufacturers to coordinate management and improve recovery rate.

- Improve recovery efficiency, reduce carbon emissions.
- Reduce unnecessary and unreasonable incineration and landfill.
- Promote circular green economy and sustainable development.
- Using technology to help traditional industries transform.

- Optimize the level of urban intelligent management and improve the ability of digital governance. Promote digital transformation and upgrading of governments, organizations and environmental protection enterprises.
- Realizing data-driven digital and intelligent garbage management.

An Intelligent Garbage Classification System
Based on Machine Learning and Deep Learning

Thanks!

EZABLE

Leading Intelligent Waste Management

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