Binary classification of bus and tram based on audio signals - code implementation

December 14, 2023

Downloading the necessary modules and libraries for the project.

[ ]:

```
# Using these lines in terminal and remember to set the environment variable to this ipynb file
# conda create --name comp.sgn.120 python=3.11.3
# conda activate comp.sgn.120
# conda install numpy=1.26.2
# pip install ipykernel --upgrade
# conda install -c conda-forge ffmpeg

# Uncomment these lines to run and install the required packages if you haven't already
# !pip install pydub==0.25.1
# !pip install tqdm==4.66.1
# !pip install librosa==0.10.1
# !pip install matplotlib==3.7.2
# !pip install scikit-learn==1.3.2
# !pip install scipy==1.11.4
# !pip install pandas==2.1.4
```

Necessary Modules and Libraries

[ ]:

```
import os

# Database loading and Feature extraction
# from pydub import AudioSegment
import librosa as lb
import librosa.display
from scipy.stats import skew, kurtosis
from scipy.signal import hamming, hann


# Representation
import matplotlib.pyplot as plt

# Data processing
import numpy as np
import pandas as pd
from tqdm import tqdm, tqdm_pandas

tqdm.pandas()
from sklearn.preprocessing import StandardScaler
from sklearn.decomposition import PCA

# Training
from sklearn.model_selection import train_test_split
from sklearn.neighbors import KNeighborsClassifier
from sklearn.svm import SVC

# Evaluation
from sklearn.metrics import accuracy_score, precision_score, recall_score
from matplotlib.colors import ListedColormap
```

Function for reading the data

[ ]:

```
def readFolder(folder):
    folder_names = []
    for root, dirs, files in os.walk(folder):
        for name in dirs:
            folder_names.append(os.path.join(root, name))
    return folder_names


def readFileInFolder(folder):
    file_lists = []
    for root, dirs, files in os.walk(folder):
        for name in files:
            file_lists.append(os.path.join(root, name))
    return file_lists
```

Function for extracting the features

[ ]:

```
def no_spectrogram_feature(data, ft1):
    ft2 = librosa.feature.zero_crossing_rate(y=data)[0]
    ft3 = librosa.feature.spectral_rolloff(y=data)[0]
    ft4 = librosa.feature.spectral_centroid(y=data)[0]
    ft5 = librosa.feature.spectral_contrast(y=data)[0]
    ft6 = librosa.feature.spectral_bandwidth(y=data)[0]

    ft1_trunc = np.hstack(
        (
            np.mean(ft1),
            np.std(ft1),
            skew(ft1),
            np.max(ft1),
            np.median(ft1),
            np.min(ft1),
        )
    )
    ft2_trunc = np.hstack(
        (
            np.mean(ft2),
            np.std(ft2),
            skew(ft2),
            np.max(ft2),
            np.median(ft2),
            np.min(ft2),
        )
    )
    ft3_trunc = np.hstack(
        (
            np.mean(ft3),
            np.std(ft3),
            skew(ft3),
            np.max(ft3),
            np.median(ft3),
            np.min(ft3),
        )
    )
    ft4_trunc = np.hstack(
        (
            np.mean(ft4),
            np.std(ft4),
            skew(ft4),
            np.max(ft4),
            np.median(ft4),
            np.min(ft4),
        )
    )
    ft5_trunc = np.hstack(
        (
            np.mean(ft5),
            np.std(ft5),
            skew(ft5),
            np.max(ft5),
            np.median(ft5),
            np.min(ft5),
        )
    )
    ft6_trunc = np.hstack(
        (
            np.mean(ft6),
            np.std(ft6),
            skew(ft6),
            np.max(ft6),
            np.median(ft6),
            np.max(ft6),
        )
    )
    return (ft1_trunc, ft2_trunc, ft3_trunc, ft4_trunc, ft5_trunc, ft6_trunc)


def spectrogram_feature(data, ft1):
    ft2 = librosa.feature.zero_crossing_rate(y=data)[0]
    ft3 = librosa.feature.spectral_rolloff(y=data)[0]
    ft4 = librosa.feature.spectral_centroid(y=data)[0]
    ft5 = librosa.feature.spectral_contrast(y=data)[0]
    ft6 = librosa.feature.spectral_bandwidth(y=data)[0]

    ft1_trunc = np.hstack(
        (
            np.mean(ft1),
            np.std(ft1),
            np.max(ft1),
            np.median(ft1),
            np.min(ft1),
        )
    )
    ft2_trunc = np.hstack(
        (
            np.mean(ft2),
            np.std(ft2),
            np.max(ft2),
            np.median(ft2),
            np.min(ft2),
        )
    )
    ft3_trunc = np.hstack(
        (
            np.mean(ft3),
            np.std(ft3),
            np.max(ft3),
            np.median(ft3),
            np.min(ft3),
        )
    )
    ft4_trunc = np.hstack(
        (
            np.mean(ft4),
            np.std(ft4),
            np.max(ft4),
            np.median(ft4),
            np.min(ft4),
        )
    )
    ft5_trunc = np.hstack(
        (
            np.mean(ft5),
            np.std(ft5),
            np.max(ft5),
            np.median(ft5),
            np.min(ft5),
        )
    )
    ft6_trunc = np.hstack(
        (
            np.mean(ft6),
            np.std(ft6),
            np.max(ft6),
            np.median(ft6),
            np.max(ft6),
        )
    )
    return (ft1_trunc, ft2_trunc, ft3_trunc, ft4_trunc, ft5_trunc, ft6_trunc)


def getEnergy(name, path=None):
    data, _ = librosa.core.load(name, sr=None)
    frame_size = 512
    hop_size = 128
    energy_features = []

    # Segmenting the audio file into frames to extract features more precisely
    for i in range(0, len(data), hop_size):
        frame = data[i : i + frame_size]
        energy_features.append(np.sum(np.power(frame, 2)))
    energy_features = np.array(energy_features)

    (
        ft1_trunc,
        ft2_trunc,
        ft3_trunc,
        ft4_trunc,
        ft5_trunc,
        ft6_trunc,
    ) = no_spectrogram_feature(data, energy_features)
    return pd.Series(
        np.hstack((ft1_trunc, ft2_trunc, ft3_trunc, ft4_trunc, ft5_trunc, ft6_trunc))
    )


def getRMS(name, path=None):
    data, _ = librosa.core.load(name, sr=None)
    frame_size = 512
    hop_size = 128
    rms_features = []

    # Segmenting the audio file into frames to extract features more precisely
    for i in range(0, len(data), hop_size):
        frame = data[i : i + frame_size]
        rms_features.append(np.sqrt(np.mean(np.power(frame, 2))))
    rms_features = np.array(rms_features)
    (
        ft1_trunc,
        ft2_trunc,
        ft3_trunc,
        ft4_trunc,
        ft5_trunc,
        ft6_trunc,
    ) = no_spectrogram_feature(data, rms_features)
    return pd.Series(
        np.hstack((ft1_trunc, ft2_trunc, ft3_trunc, ft4_trunc, ft5_trunc, ft6_trunc))
    )


def getSpec(name, path=None):
    n_fft = 512
    hop_size = 128
    data, _ = librosa.core.load(name, sr=None)
    spectrogram = lb.amplitude_to_db(
        np.abs(lb.stft(data, n_fft=n_fft, hop_length=hop_size))
    )
    (
        ft1_trunc,
        ft2_trunc,
        ft3_trunc,
        ft4_trunc,
        ft5_trunc,
        ft6_trunc,
    ) = spectrogram_feature(data, spectrogram)
    return pd.Series(
        np.hstack((ft1_trunc, ft2_trunc, ft3_trunc, ft4_trunc, ft5_trunc, ft6_trunc))
    )


def getMel(name, path=None):
    n_mel = 40
    hop_size = 128
    n_fft = 512
    frame_size = 512
    data, _ = librosa.core.load(name, sr=None)
    spec = np.abs(lb.stft(data, n_fft=n_fft, hop_length=hop_size))
    mel = lb.feature.melspectrogram(S=spec, n_mels=n_mel)
    (
        ft1_trunc,
        ft2_trunc,
        ft3_trunc,
        ft4_trunc,
        ft5_trunc,
        ft6_trunc,
    ) = spectrogram_feature(data, mel)
    return pd.Series(
        np.hstack((ft1_trunc, ft2_trunc, ft3_trunc, ft4_trunc, ft5_trunc, ft6_trunc))
    )


def getLogMel(name, path=None):
    n_mel = 40
    hop_size = 128
    n_fft = 512
    data, _ = librosa.core.load(name, sr=22050)
    spec = np.abs(lb.stft(data, n_fft=n_fft, hop_length=hop_size))
    mel = lb.feature.melspectrogram(S=spec, n_mels=n_mel)
    logmel = lb.power_to_db(mel)
    (
        ft1_trunc,
        ft2_trunc,
        ft3_trunc,
        ft4_trunc,
        ft5_trunc,
        ft6_trunc,
    ) = spectrogram_feature(data, logmel)
    return pd.Series(
        np.hstack((ft1_trunc, ft2_trunc, ft3_trunc, ft4_trunc, ft5_trunc, ft6_trunc))
    )
```

```
def getMFCC(name, path):
    n_mel = 40
    hop_size = 128
    n_fft = 512
    data, _ = librosa.core.load(name, sr=None)

    try:
        ft1 = lb.feature.mfcc(
            y=data, n_mfcc=n_mel, hop_length=hop_size, norm="ortho", n_fft=n_fft
        )
        (
            ft1_trunc,
            ft2_trunc,
            ft3_trunc,
            ft4_trunc,
            ft5_trunc,
            ft6_trunc,
        ) = spectrogram_feature(data, ft1)
        return pd.Series(
            np.hstack(
                (ft1_trunc, ft2_trunc, ft3_trunc, ft4_trunc, ft5_trunc,␣
 ↪ft6_trunc)
            )
        )
    except:
        print("bad file")

        return pd.Series([0] * 210)


def getCQT(name, path=None):
    n_mel = 40
    hop_size = 128
    n_fft = 512
    data, _ = librosa.core.load(name, sr=22050)
    cqt = lb.amplitude_to_db(np.abs(lb.cqt(data, sr=22050,␣
 ↪hop_length=hop_size)))
    (
        ft1_trunc,
        ft2_trunc,
        ft3_trunc,
        ft4_trunc,
        ft5_trunc,
        ft6_trunc,
    ) = spectrogram_feature(data, cqt)
    return pd.Series(
        np.hstack((ft1_trunc, ft2_trunc, ft3_trunc, ft4_trunc, ft5_trunc,␣
 ↪ft6_trunc))
    )
```

Evaluating function

[ ]:
```
def printAccuracy(y_test, y_pred):
    accuracy = accuracy_score(y_test, y_pred)
    precision = precision_score(y_test, y_pred, average = 'macro',␣
 ↪zero_division=1)
    recall = recall_score(y_test, y_pred, average = 'macro')

    print("Accuracy: ", accuracy)
    print("Precision: ", precision)
    print("Recall: ", recall)
    return accuracy, precision, recall
```

Data preprocessing

[ ]:
```
# Tram_Train: https://freesound.org/people/publictransport/packs/36726/
# Tram_Train: https://freesound.org/people/ali.abdelsalam/packs/36722/
# Bus_Train: https://freesound.org/people/emmakyllikki/packs/36810/
# Bus_Train: https://freesound.org/people/glingden/packs/36807/
# Tram_Test: My own recording
# Bus_Test: My own recording
folder_list = readFolder("audio")
folder_to_read = ["Bus_Test", "Bus_Train", "Tram_Test", "Tram_Train"]
bus_test = []
bus_train = []
tram_test = []
tram_train = []
label = {}
for folder in folder_list:
    # Read all the files and append to the list of files
    files = readFileInFolder(folder)
    for name in folder_to_read:
        if name in folder:
            # Append the files to the corresponding list
            if name == "Bus_Test":
                bus_test = files
                for file in files:
                    label[file] = "bus"
            elif name == "Bus_Train":
                bus_train = files
                for file in files:
                    label[file] = "bus"
            elif name == "Tram_Test":
                tram_test = files
                for file in files:
                    label[file] = "tram"
            elif name == "Tram_Train":
                tram_train = files
                for file in files:
                    label[file] = "tram"
```

[ ]:

```
# Prepare Data
train_data = pd.DataFrame()
train_data["fname"] = bus_train + tram_train
test_data = pd.DataFrame()
test_data["fname"] = bus_test + tram_test

train_data = train_data["fname"].progress_apply(getMFCC, path = None)
print("done loading train mfcc")
test_data = test_data["fname"].progress_apply(getMFCC, path = None)
print("done loading test mfcc")
```

```
100%|      | 98/98 [00:22<00:00,  4.27it/s]

done loading train mfcc

100%|      | 18/18 [00:06<00:00,  2.70it/s]

done loading test mfcc
```

[ ]:

```
train_data["fname"] = bus_train + tram_train
train_data["label"] = train_data["fname"].apply(lambda x: label[x])
test_data["fname"] = bus_test + tram_test
test_data["label"] = test_data["fname"].apply(lambda x: label[x])
```

[ ]:

```
def getDataset(train_data, test_data):
    X = train_data.drop(['label', 'fname'], axis=1)
    feature_names = list(X.columns)
    X = X.values

    labels = np.sort(np.unique(train_data.label.values))

    num_class = len(labels)
    c2i = {}
    i2c = {}
    for i, c in enumerate(labels):
        c2i[c] = i
        i2c[i] = c
    y = np.array([c2i[x] for x in train_data.label.values])
    X_test = test_data.drop(['label', 'fname'], axis=1).values
    y_test = np.array([c2i[x] for x in test_data.label.values])
    return (X, y, X_test, y_test, feature_names, num_class, c2i, i2c)
```

[ ]:

```
X, y, X_test, y_test, feature_names, num_class, c2i, i2c = getDataset(
    train_data, test_data)
```

[ ]:

```
# A function that exporting the csv file from the beginning of the
def exportCSV(y_pred, y_test, filename, bus_test=bus_test, tram_test=tram_test,␣
 ↪i2c=i2c):
    # convert the binary data into a class label (bus or tram)
    y_pred_label = []
    for i in range(len(y_pred)):
        y_pred_label.append(i2c[y_pred[i]])
    y_pred_label = np.array(y_pred_label)


    # convert the binary data into a class label (bus or tram)
    y_test_label = []
    for i in range(len(y_test)):
        y_test_label.append(i2c[y_test[i]])
    y_test_label = np.array(y_test_label)

    y_test_name = []
    for i in range(len(bus_test)):
        y_test_name.append(os.path.basename(bus_test[i]))
    for i in range(len(tram_test)):
        y_test_name.append(os.path.basename(tram_test[i]))
    y_test_name = np.array(y_test_name)


    # Export the CSV file using y_test_name, y_pred_label, and y_test_label
    df = pd.DataFrame(
        {'fname': y_test_name, 'y_pred': y_pred_label, 'y_test': y_test_label})
    df.to_csv(filename, index=False)
```

[ ]:

```
def dataPreprocessing(X, X_test):
    # Apply scaling for PCA
    scaler = StandardScaler()
    scaler.fit_transform(X)
    X_scaled = scaler.transform(X)
    X_test_scaled = scaler.transform(X_test)

    # Apply PCA for dimension reduction (if the model is too slow to train,␣
 ↪reduce the number of components)
    # try:
    #     pca = PCA(n_components=65).fit(X_scaled)
    #     X_pca = pca.transform(X_scaled)
    #     X_test_pca = pca.transform(X_test_scaled)
    #     print(sum(pca.explained_variance_ratio_))
    # except:
    #     pca = PCA(n_components=30).fit(X_scaled)
    #     X_pca = pca.transform(X_scaled)
    #     X_test_pca = pca.transform(X_test_scaled)
    #     print(sum(pca.explained_variance_ratio_))
    pca = PCA(n_components=2).fit(X_scaled)
    X_pca = pca.transform(X_scaled)
    X_test_pca = pca.transform(X_test_scaled)
    print(sum(pca.explained_variance_ratio_))
    # X_pca = X_scaled
    # X_test_pca = X_test_scaled
    return X_scaled, X_test_scaled, X_pca, X_test_pca
```

[ ]:

```
def plot_decision_boundary(X, y, model, title):
    # Create color maps
    cmap_light = ListedColormap(['#FFAAAA', '#AAFFAA', '#AAAAFF'])
    cmap_bold = ListedColormap(['#FF0000', '#00FF00', '#0000FF'])

    h = .02  # step size in the mesh
    # Calculate min, max and limits
    x_min, x_max = X[:, 0].min() - 1, X[:, 0].max() + 1
    y_min, y_max = X[:, 1].min() - 1, X[:, 1].max() + 1
    xx, yy = np.meshgrid(np.arange(x_min, x_max, h), np.arange(y_min, y_max, h))

    # Predict class using model and data
    Z = model.predict(np.c_[xx.ravel(), yy.ravel()])

    # Put the result into a color plot
    Z = Z.reshape(xx.shape)
    plt.figure()
    plt.pcolormesh(xx, yy, Z, cmap=cmap_light)

    # Plot also the training points
    plt.scatter(X[:, 0], X[:, 1], c=y, cmap=cmap_bold)
    plt.xlim(xx.min(), xx.max())
    plt.ylim(yy.min(), yy.max())
    plt.title(title)
    plt.show()
```

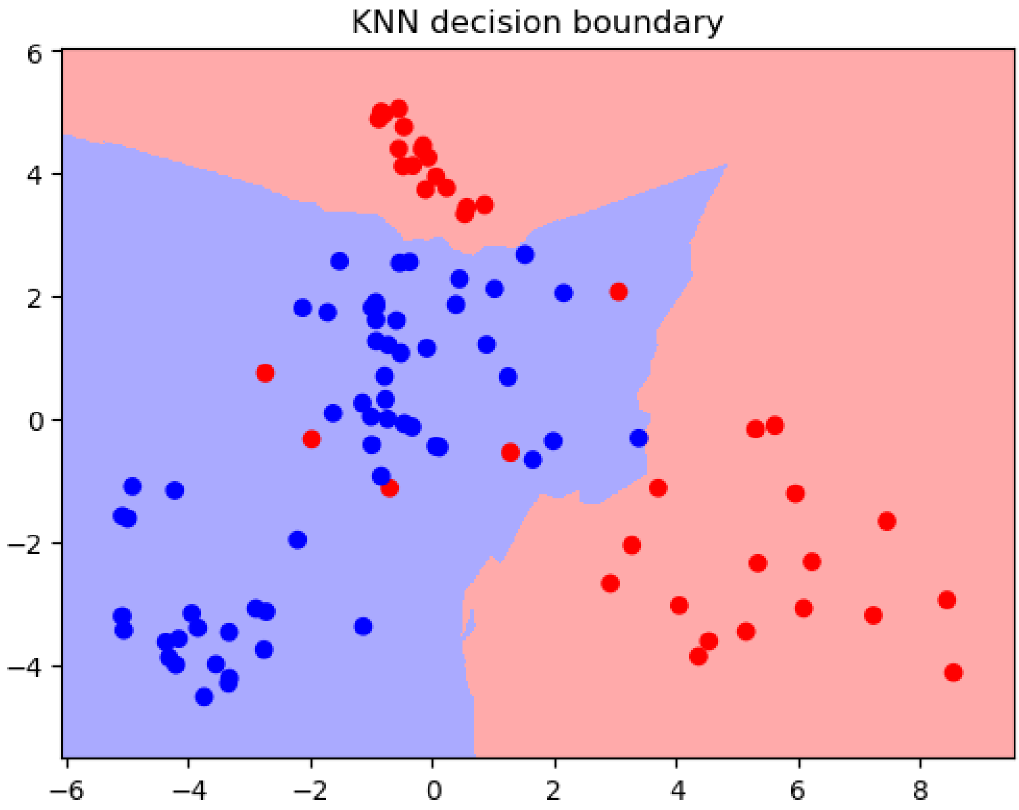
[ ]:

```
def dataProcessAndTrainAndEvaluate(X_pca, y, feature="MFCC"):
    # Build a KNN model
    X_train, X_val, y_train, y_val = train_test_split(
        X_pca, y, test_size=0.01, random_state=42, shuffle=True)

    knn = KNeighborsClassifier(n_neighbors=5)
    knn.fit(X_train, y_train)

    # Test the kNN model with the test data
    y_pred = knn.predict(X_test_pca)
    print("KNN: ")
    printAccuracy(y_test, y_pred)
    exportCSV(y_pred, y_test, f'{feature}_KNN_output.csv')

    # Build a SVM model
    X_train, X_val, y_train, y_val = train_test_split(
        X_pca, y, test_size=0.01, random_state=42, shuffle=True)
    clf = SVC(kernel='rbf', probability=True)
    clf.fit(X_train, y_train)

    # Test the SVM model with the test data
    y_pred = clf.predict(X_test_pca)
    print("SVM: ")
    printAccuracy(y_test, y_pred)
    print(f"Decision Boundary for kNN classfiier with {feature} features, k=5")
    plot_decision_boundary(X_train, y_train, knn, "KNN decision boundary")
    print(f"Decision Boundary for SVM classfiier with {feature} features")
    plot_decision_boundary(X_train, y_train, clf, "SVM decision boundary")
    exportCSV(y_pred, y_test, f'{feature}_SVM_output.csv')
```

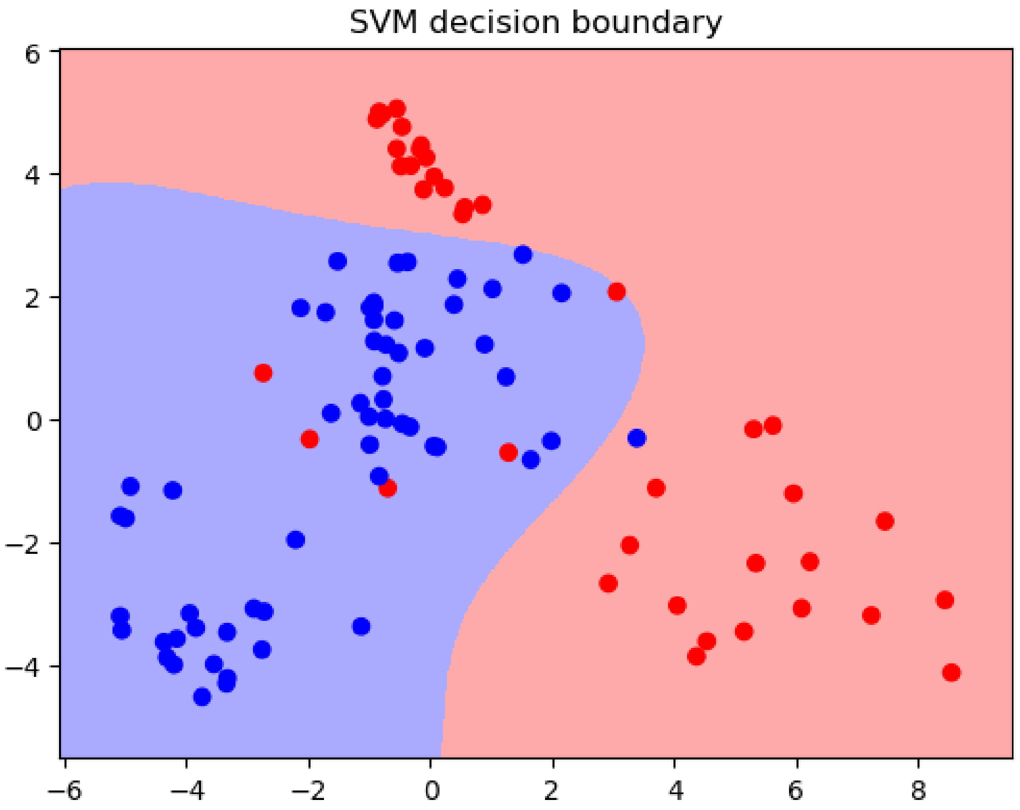
[ ]:

```
X_scaled, X_test_scaled, X_pca, X_test_pca = dataPreprocessing(X, X_test)
dataProcessAndTrainAndEvaluate(X_pca, y)
```

```
0.5945425964362843
KNN:
Accuracy:  0.9444444444444444
Precision:  0.9545454545454546
Recall:  0.9375
SVM:
Accuracy:  0.8888888888888888
Precision:  0.9166666666666667
Recall:  0.875
Decision Boundary for kNN classfiier with MFCC features, k=5
```



Decision Boundary for SVM classfiier with MFCC features



```
[ ]: # Continuing with other features
     train_data_list = []
     test_data_list = []
     feature_names_list = ["energy", "rms", "spec", "mel", "logmel", "cqt"]
     feature_functions = [getEnergy, getRMS, getSpec, getMel, getLogMel, getCQT]
     for i in range(len(feature_functions)):
         train_data = pd.DataFrame()
         train_data["fname"] = bus_train + tram_train
         test_data = pd.DataFrame()
         test_data["fname"] = bus_test + tram_test

         train_data = train_data["fname"].progress_apply(
             feature_functions[i], path=None)
         print("done loading train", feature_names_list[i])
         test_data = test_data["fname"].progress_apply(
             feature_functions[i], path=None)
         print("done loading test", feature_names_list[i])

         train_data["fname"] = bus_train + tram_train
         train_data["label"] = train_data["fname"].apply(lambda x: label[x])
         test_data["fname"] = bus_test + tram_test
```

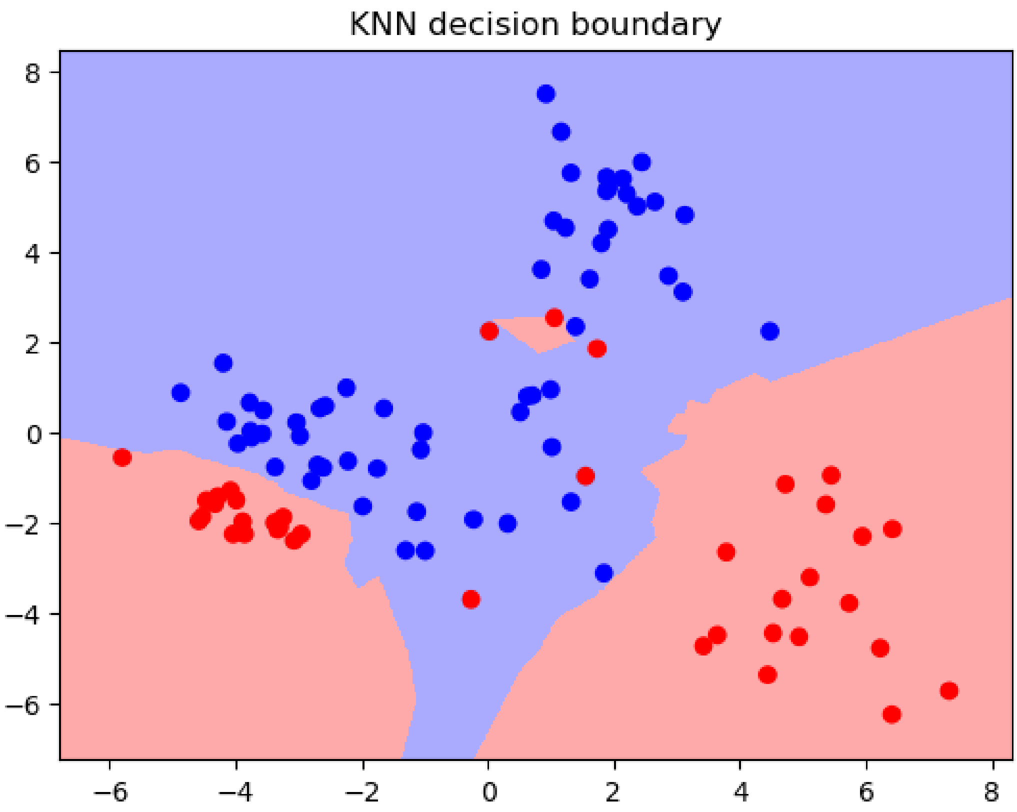
```
    test_data["label"] = test_data["fname"].apply(lambda x: label[x])

    train_data_list.append(train_data)
    test_data_list.append(test_data)
```

```
100%|      | 98/98 [00:22<00:00,  4.27it/s]

done loading train energy

100%|      | 18/18 [00:08<00:00,  2.22it/s]

done loading test energy

100%|      | 98/98 [00:29<00:00,  3.28it/s]

done loading train rms

100%|      | 18/18 [00:09<00:00,  1.95it/s]

done loading test rms

100%|      | 98/98 [00:23<00:00,  4.15it/s]

done loading train spec

100%|      | 18/18 [00:07<00:00,  2.53it/s]

done loading test spec

100%|      | 98/98 [00:22<00:00,  4.35it/s]

done loading train mel

100%|      | 18/18 [00:06<00:00,  2.88it/s]

done loading test mel

100%|      | 98/98 [00:12<00:00,  8.06it/s]

done loading train logmel

100%|      | 18/18 [00:03<00:00,  4.90it/s]

done loading test logmel

100%|      | 98/98 [00:19<00:00,  4.94it/s]

done loading train cqt

100%|      | 18/18 [00:05<00:00,  3.17it/s]

done loading test cqt
```

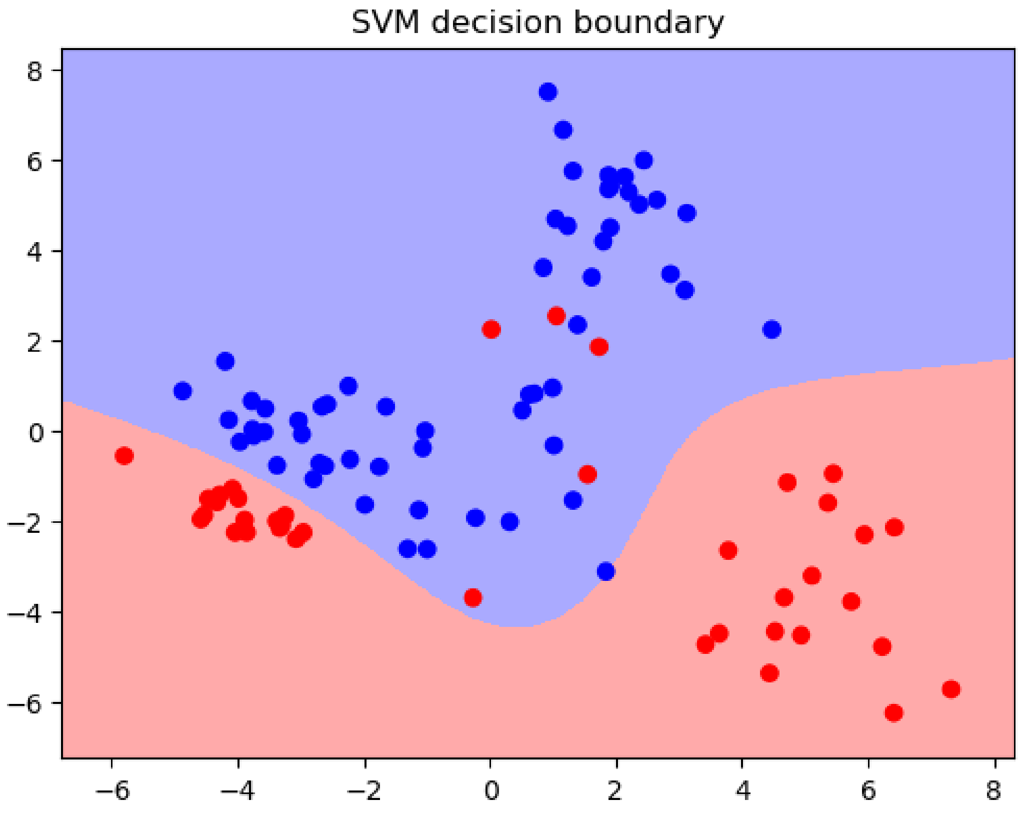
[ ]:

```
for i in range(len(train_data_list)):
    print("Feature:", feature_names_list[i])

    X, y, X_test, y_test, feature_names, num_class, c2i, i2c = getDataset(
        train_data_list[i], test_data_list[i])

    X_scaled, X_test_scaled, X_pca, X_test_pca = dataPreprocessing(X, X_test)
    # print(feature_names_list[i])
    dataProcessAndTrainAndEvaluate(X_pca, y, feature_names_list[i])
    print()
```

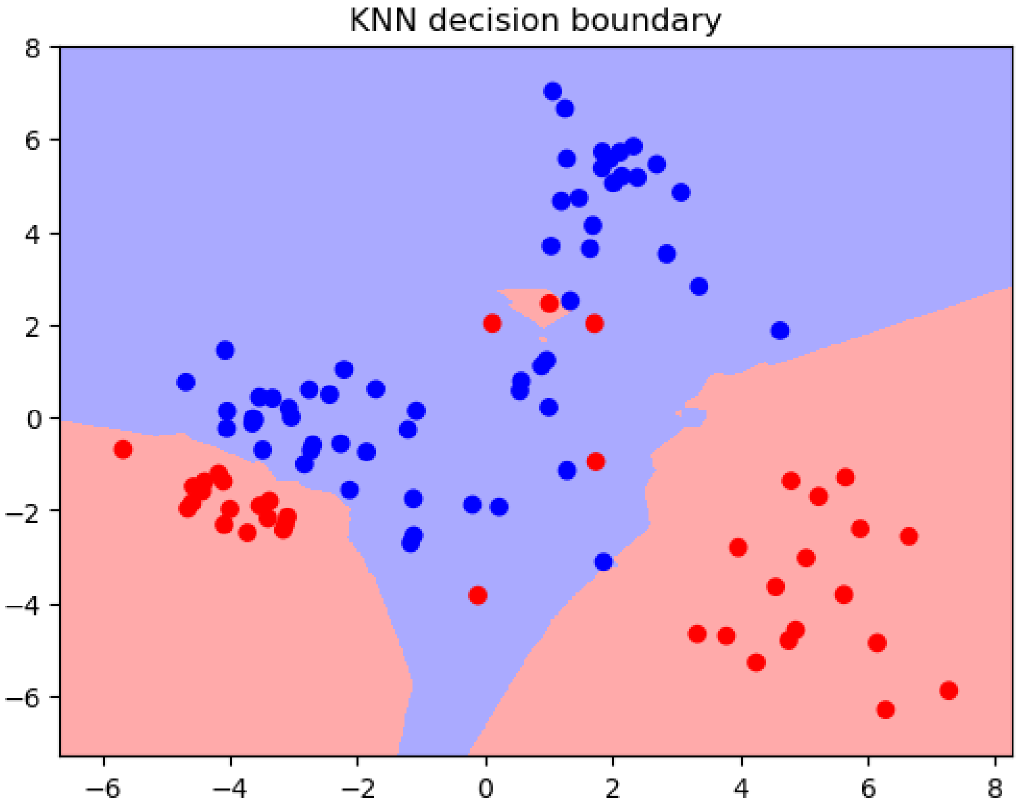
```
Feature: energy
0.5800022020646739
KNN:
Accuracy:  0.6666666666666666
Precision:  0.7857142857142857
Recall:  0.7
SVM:
Accuracy:  0.6666666666666666
Precision:  0.7857142857142857
Recall:  0.7
Decision Boundary for kNN classfiier with energy features, k=5
```



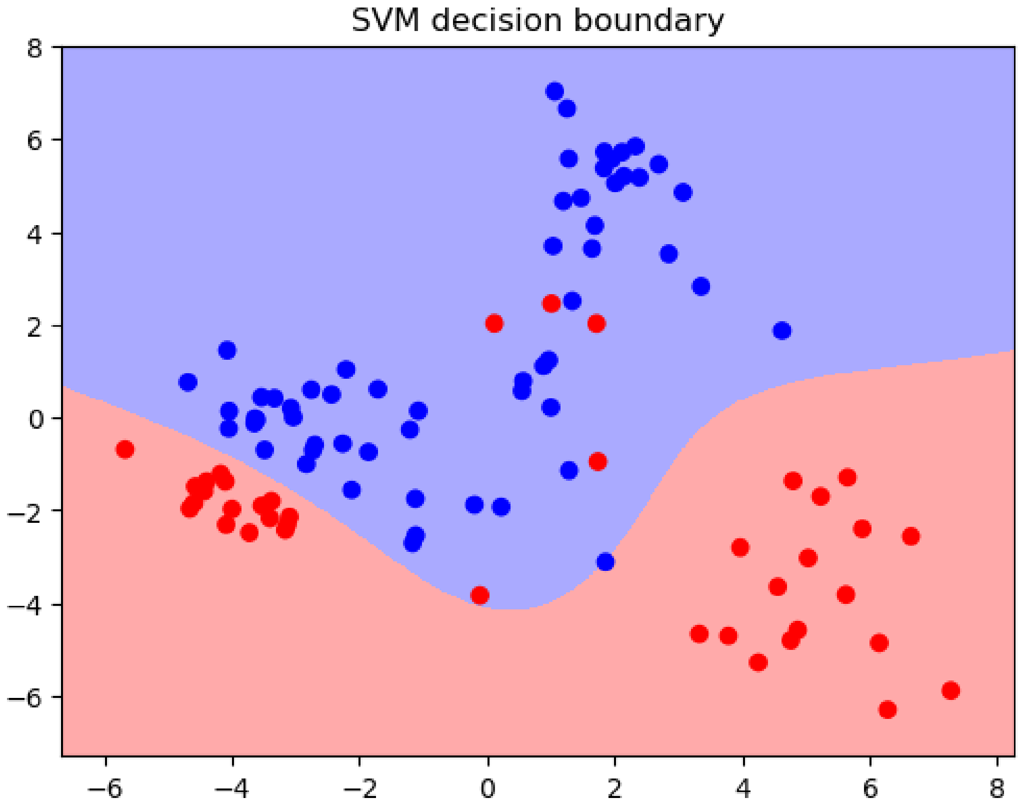
```
Decision Boundary for SVM classfiier with energy features
```



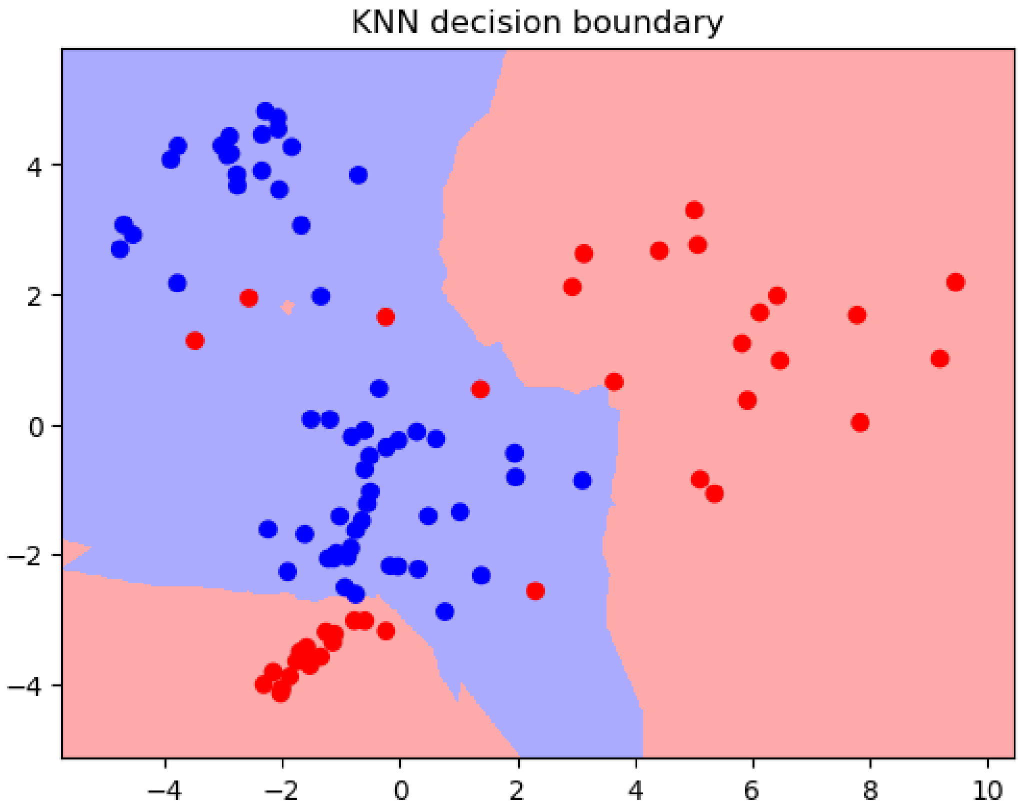
```
Feature: rms
0.5864776323324902
KNN:
Accuracy:  0.6666666666666666
Precision:  0.7857142857142857
Recall:  0.7
SVM:
Accuracy:  0.6666666666666666
Precision:  0.7857142857142857
Recall:  0.7
Decision Boundary for kNN classfiier with rms features, k=5
```



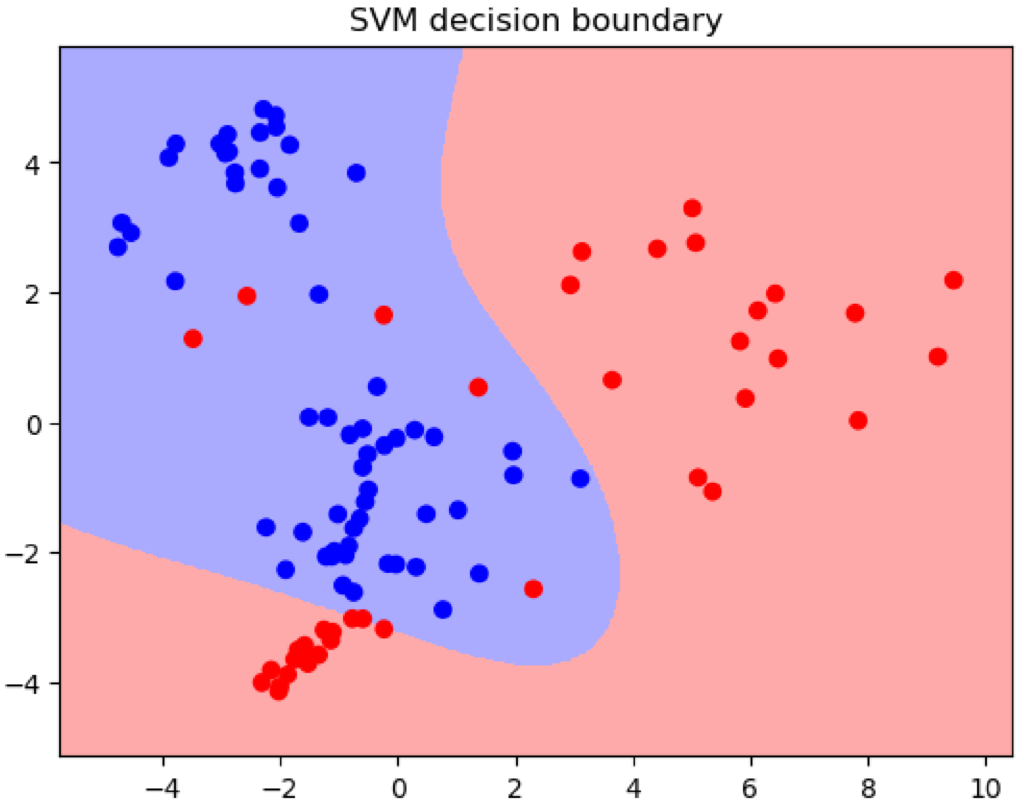
`Decision Boundary for SVM classfiier with rms features`



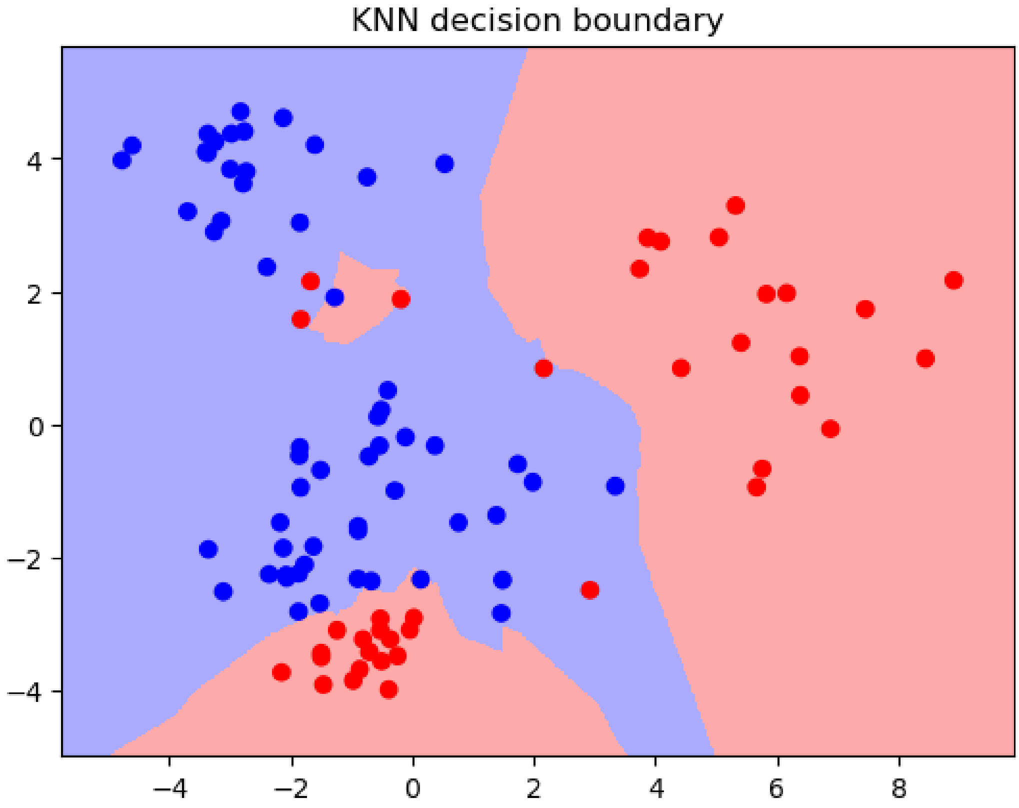
```
Feature: spec
0.5665661624004011
KNN:
Accuracy:  0.6111111111111112
Precision:  0.6692307692307693
Recall:  0.6375
SVM:
Accuracy:  0.6666666666666666
Precision:  0.7083333333333334
Recall:  0.6875
Decision Boundary for kNN classfiier with spec features, k=5
```



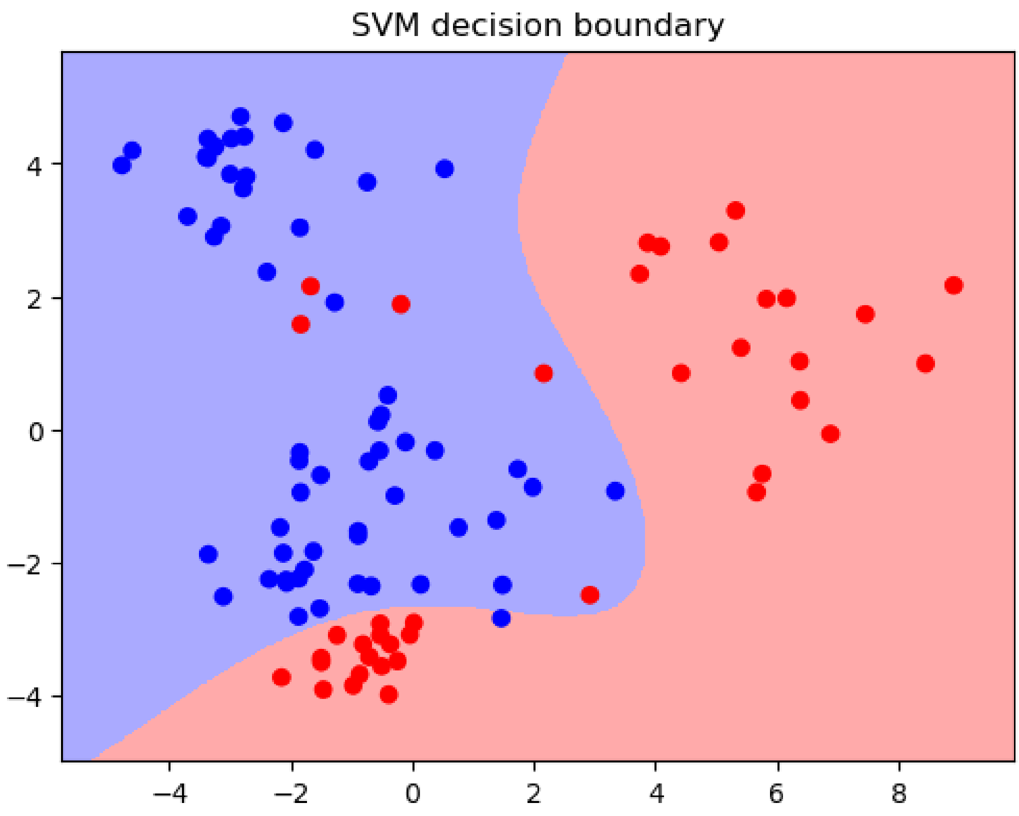
```
Decision Boundary for SVM classfiier with spec features
```



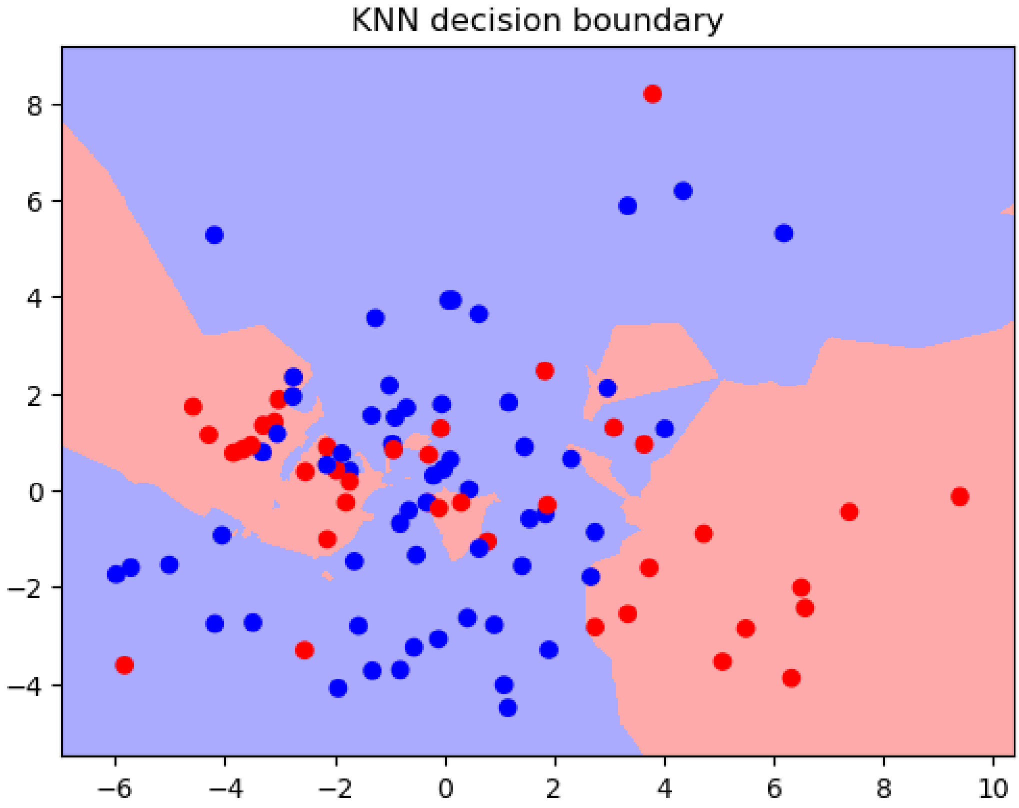
```
Feature: mel
0.5647717944739095
KNN:
Accuracy:  0.6666666666666666
Precision:  0.7857142857142857
Recall:  0.7
SVM:
Accuracy:  0.5555555555555556
Precision:  0.5833333333333333
Recall:  0.575
Decision Boundary for kNN classfiier with mel features, k=5
```



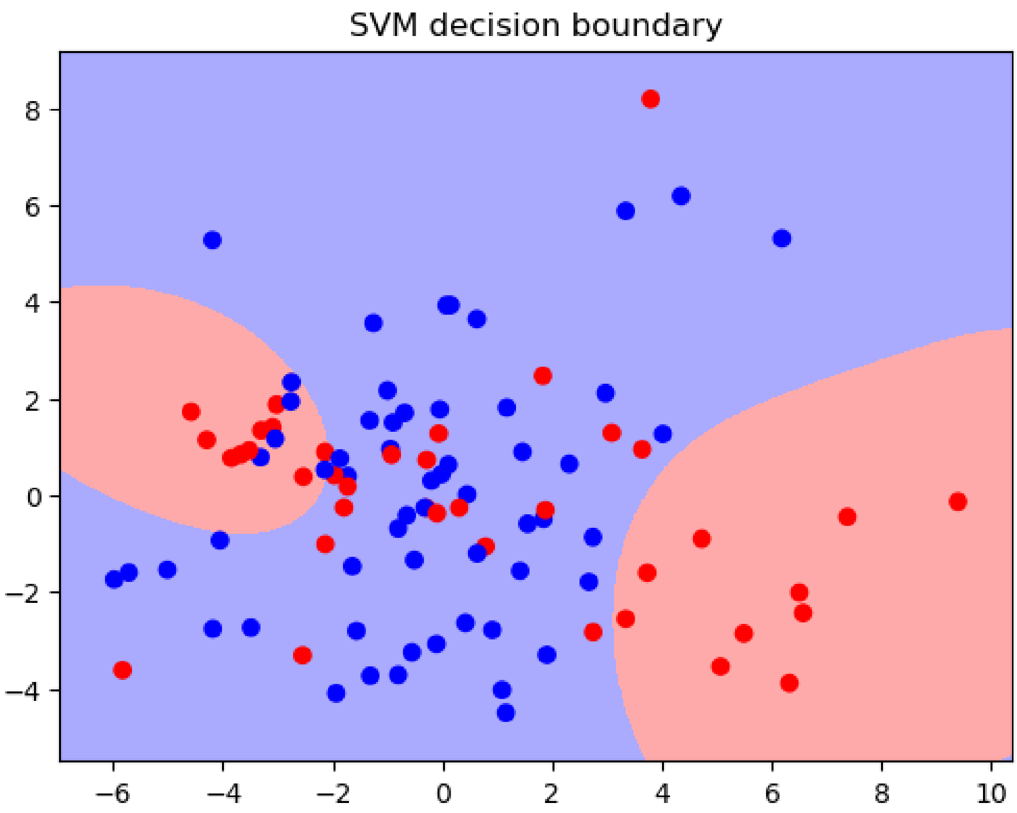
Decision Boundary for SVM classfiier with mel features



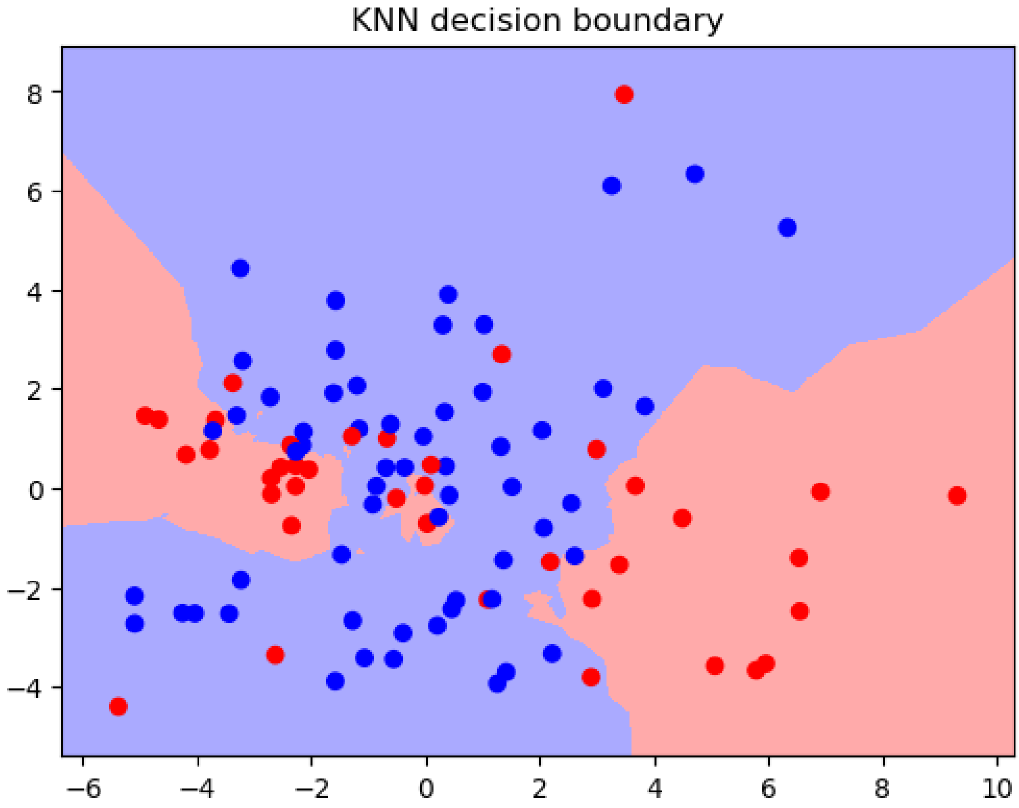
```
Feature: logmel
0.5256775065267434
KNN:
Accuracy:  0.2777777777777778
Precision:  0.2792207792207792
Recall:  0.2875
SVM:
Accuracy:  0.1111111111111111
Precision:  0.08333333333333333
Recall:  0.125
Decision Boundary for kNN classfiier with logmel features, k=5
```



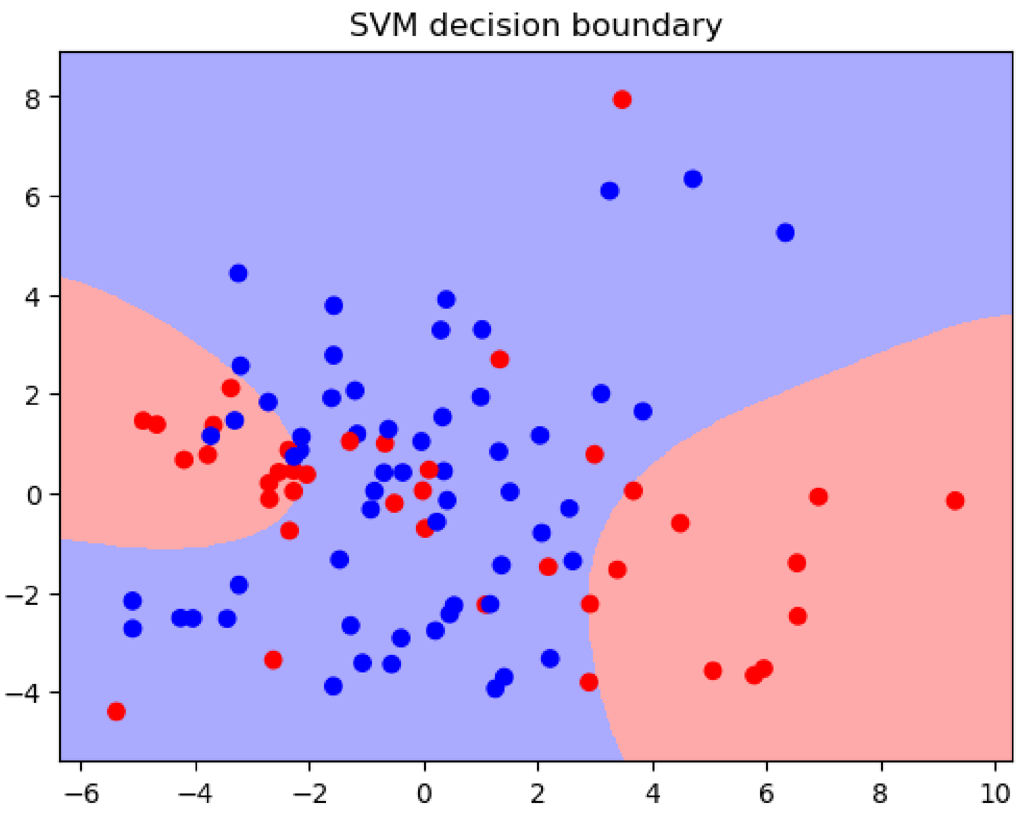
Decision Boundary for SVM classfiier with logmel features



```
Feature: cqt
0.516667622021522
KNN:
Accuracy:  0.5555555555555556
Precision:  0.55
Recall:  0.55
SVM:
Accuracy:  0.16666666666666666
Precision:  0.11538461538461539
Recall:  0.1875
Decision Boundary for kNN classfiier with cqt features, k=5
```



Decision Boundary for SVM classfiier with cqt features



```
[ ]: # Combine the content of the csv files into 1 csv file, keep the fname and real␣
      ↪lavel, and combine the predicted label into different columns with the␣
      ↪feature name as the column name
     # energy_KNN_output.csv, logmel_KNN_output.csv, mel_KNN_output.csv,␣
      ↪rms_KNN_output.csv, spec_KNN_output.csv, MFCC_KNN_output.csv, cqt_KNN_output.
      ↪csv
     with open('energy_KNN_output.csv') as f:
         energy_KNN = pd.read_csv(f)
     os.remove('energy_KNN_output.csv')
     with open('logmel_KNN_output.csv') as f:
         logmel_KNN = pd.read_csv(f)
     os.remove('logmel_KNN_output.csv')
     with open('mel_KNN_output.csv') as f:
         mel_KNN = pd.read_csv(f)
     os.remove('mel_KNN_output.csv')
     with open('rms_KNN_output.csv') as f:
         rms_KNN = pd.read_csv(f)
     os.remove('rms_KNN_output.csv')
     with open('spec_KNN_output.csv') as f:
```

```
    spec_KNN = pd.read_csv(f)
os.remove('spec_KNN_output.csv')
with open('MFCC_KNN_output.csv') as f:
    MFCC_KNN = pd.read_csv(f)
os.remove('MFCC_KNN_output.csv')
with open('cqt_KNN_output.csv') as f:
    cqt_KNN = pd.read_csv(f)
os.remove('cqt_KNN_output.csv')

energy_KNN.rename(columns={'y_pred': 'energy'}, inplace=True)
logmel_KNN.rename(columns={'y_pred': 'logmel'}, inplace=True)
mel_KNN.rename(columns={'y_pred': 'mel'}, inplace=True)
rms_KNN.rename(columns={'y_pred': 'rms'}, inplace=True)
spec_KNN.rename(columns={'y_pred': 'spec'}, inplace=True)
MFCC_KNN.rename(columns={'y_pred': 'MFCC'}, inplace=True)
cqt_KNN.rename(columns={'y_pred': 'cqt'}, inplace=True)

# Concatenate the dataframes, deleting the duplicate columns
KNN_concat = pd.concat([energy_KNN, logmel_KNN, mel_KNN, rms_KNN, spec_KNN,␣
 ↪MFCC_KNN, cqt_KNN], axis=1)
KNN_concat = KNN_concat.loc[:,~KNN_concat.columns.duplicated()]
print(KNN_concat)

# energy_SVM_output.csv, logmel_SVM_output.csv, mel_SVM_output.csv,␣
 ↪rms_SVM_output.csv, spec_SVM_output.csv, MFCC_SVM_output.csv, cqt_SVM_output.
 ↪csv
with open('energy_SVM_output.csv') as f:
    energy_SVM = pd.read_csv(f)
os.remove('energy_SVM_output.csv')

with open('logmel_SVM_output.csv') as f:
    logmel_SVM = pd.read_csv(f)
os.remove('logmel_SVM_output.csv')

with open('mel_SVM_output.csv') as f:
    mel_SVM = pd.read_csv(f)
os.remove('mel_SVM_output.csv')

with open('rms_SVM_output.csv') as f:
    rms_SVM = pd.read_csv(f)
os.remove('rms_SVM_output.csv')

with open('spec_SVM_output.csv') as f:
    spec_SVM = pd.read_csv(f)
os.remove('spec_SVM_output.csv')

with open('MFCC_SVM_output.csv') as f:
    MFCC_SVM = pd.read_csv(f)
os.remove('MFCC_SVM_output.csv')

with open('cqt_SVM_output.csv') as f:
    cqt_SVM = pd.read_csv(f)
os.remove('cqt_SVM_output.csv')

energy_SVM.rename(columns={'y_pred': 'energy'}, inplace=True)
logmel_SVM.rename(columns={'y_pred': 'logmel'}, inplace=True)
mel_SVM.rename(columns={'y_pred': 'mel'}, inplace=True)
rms_SVM.rename(columns={'y_pred': 'rms'}, inplace=True)
spec_SVM.rename(columns={'y_pred': 'spec'}, inplace=True)
MFCC_SVM.rename(columns={'y_pred': 'MFCC'}, inplace=True)
cqt_SVM.rename(columns={'y_pred': 'cqt'}, inplace=True)

# Concatenate the dataframes, deleting the duplicate columns
SVM_concat = pd.concat([energy_SVM, logmel_SVM, mel_SVM, rms_SVM, spec_SVM,␣
  ↪MFCC_SVM, cqt_SVM], axis=1)
SVM_concat = SVM_concat.loc[:,~SVM_concat.columns.duplicated()]
# print(SVM_concat)
```

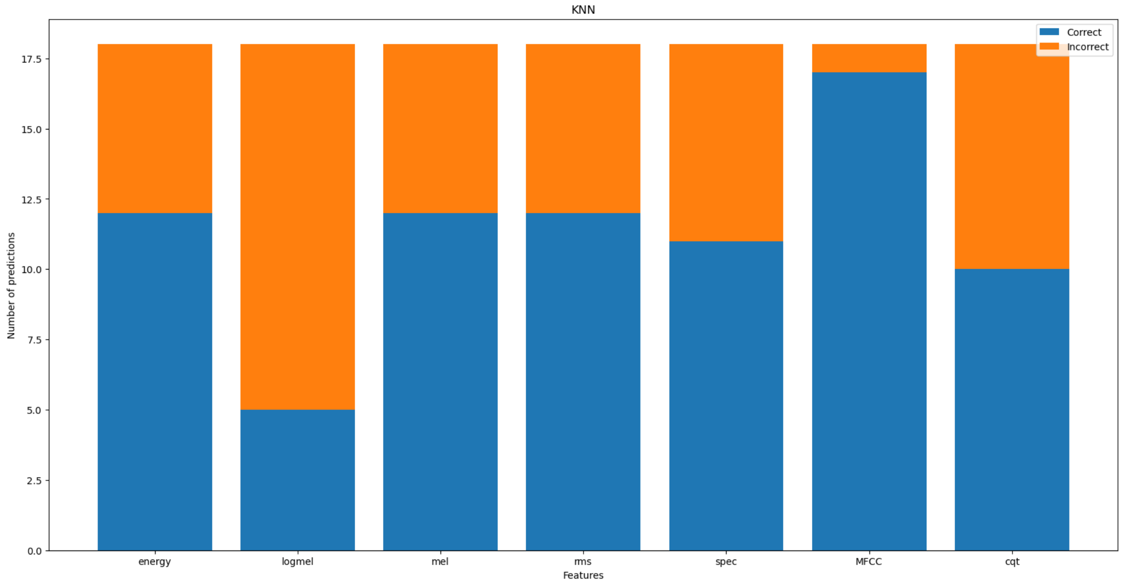
```
         fname energy y_test logmel   mel   rms  spec  MFCC   cqt
0    Bus_1.wav    bus    bus   tram   bus   bus   bus   bus  tram
1   Bus_10.wav    bus    bus   tram   bus   bus   bus   bus  tram
2    Bus_2.wav   tram    bus   tram  tram  tram  tram   bus  tram
3    Bus_3.wav   tram    bus   tram  tram  tram  tram   bus   bus
4    Bus_4.wav   tram    bus   tram  tram  tram  tram   bus   bus
5    Bus_5.wav    bus    bus    bus   bus   bus   bus   bus   bus
6    Bus_6.wav    bus    bus    bus   bus   bus   bus   bus   bus
7    Bus_7.wav   tram    bus   tram  tram  tram  tram   bus   bus
8    Bus_8.wav   tram    bus   tram  tram  tram  tram   bus  tram
9    Bus_9.wav   tram    bus   tram  tram  tram  tram   bus   bus
10  Tram_1.wav   tram   tram   tram  tram  tram  tram  tram  tram
11  Tram_2.wav   tram   tram    bus  tram  tram  tram  tram   bus
12  Tram_3.wav   tram   tram    bus  tram  tram  tram  tram   bus
13  Tram_4.wav   tram   tram    bus  tram  tram  tram  tram  tram
14  Tram_5.wav   tram   tram    bus  tram  tram  tram  tram   bus
15  Tram_6.wav   tram   tram   tram  tram  tram  tram  tram  tram
16  Tram_7.wav   tram   tram    bus  tram  tram  tram  tram   bus
17  Tram_8.wav   tram   tram   tram  tram  tram   bus   bus  tram
```

[ ]:

```
# Print the histogram, counting the number of correct predictions and incorrect␣
  ↪predictions for each feature by comparing the predicted label which has been␣
  ↪changed by the name and the real label
# KNN
# Calculate the number of correct predictions and incorrect predictions for␣
  ↪each feature
```

```
energy_KNN_correct = 0
energy_KNN_incorrect = 0
logmel_KNN_correct = 0
logmel_KNN_incorrect = 0
mel_KNN_correct = 0
mel_KNN_incorrect = 0
rms_KNN_correct = 0
rms_KNN_incorrect = 0
spec_KNN_correct = 0
spec_KNN_incorrect = 0
MFCC_KNN_correct = 0
MFCC_KNN_incorrect = 0
cqt_KNN_correct = 0
cqt_KNN_incorrect = 0

for i in range(len(KNN_concat)):
    if KNN_concat['energy'][i] == KNN_concat['y_test'][i]:
        energy_KNN_correct += 1
    else:
        energy_KNN_incorrect += 1
    if KNN_concat['logmel'][i] == KNN_concat['y_test'][i]:
        logmel_KNN_correct += 1
    else:
        logmel_KNN_incorrect += 1
    if KNN_concat['mel'][i] == KNN_concat['y_test'][i]:
        mel_KNN_correct += 1
    else:
        mel_KNN_incorrect += 1
    if KNN_concat['rms'][i] == KNN_concat['y_test'][i]:
        rms_KNN_correct += 1
    else:
        rms_KNN_incorrect += 1
    if KNN_concat['spec'][i] == KNN_concat['y_test'][i]:
        spec_KNN_correct += 1
    else:
        spec_KNN_incorrect += 1
    if KNN_concat['MFCC'][i] == KNN_concat['y_test'][i]:
        MFCC_KNN_correct += 1
    else:
        MFCC_KNN_incorrect += 1
    if KNN_concat['cqt'][i] == KNN_concat['y_test'][i]:
        cqt_KNN_correct += 1
    else:
        cqt_KNN_incorrect += 1
# add to feature_names_list MFCC before cqt
feature_names_list = ["energy", "logmel", "mel", "rms", "spec", "MFCC", "cqt"]
```

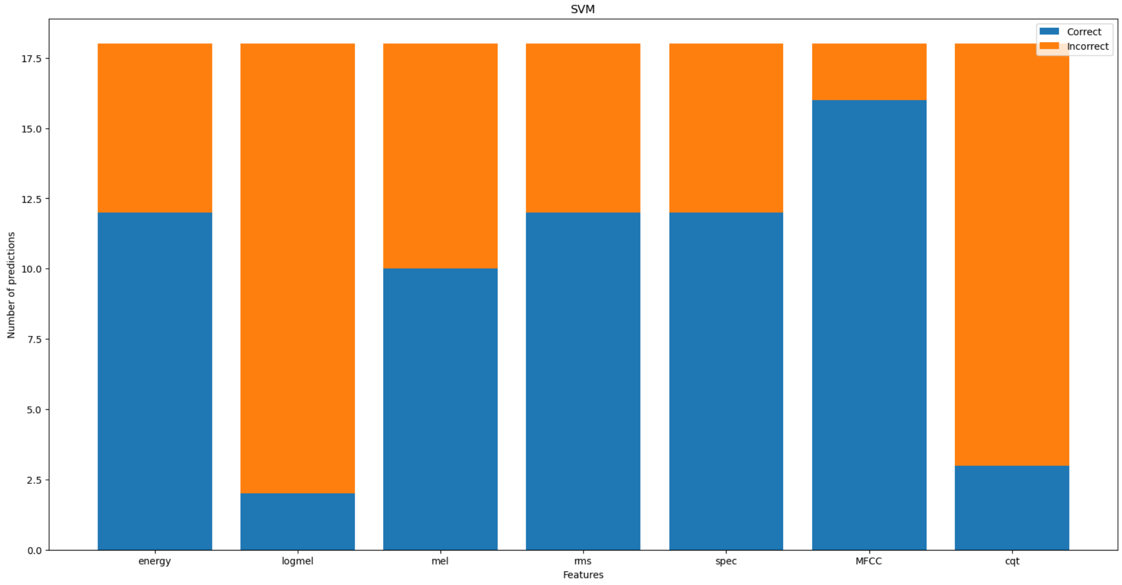
```
# Plot the diagram with the number of correct predictions and incorrect␣
 ↪predictions for each feature
plt.figure(figsize=(20,10))
plt.bar(feature_names_list, [energy_KNN_correct, logmel_KNN_correct,␣
 ↪mel_KNN_correct, rms_KNN_correct, spec_KNN_correct, MFCC_KNN_correct,␣
 ↪cqt_KNN_correct], label="Correct")
plt.bar(feature_names_list, [energy_KNN_incorrect, logmel_KNN_incorrect,␣
 ↪mel_KNN_incorrect, rms_KNN_incorrect, spec_KNN_incorrect,␣
 ↪MFCC_KNN_incorrect, cqt_KNN_incorrect], bottom=[energy_KNN_correct,␣
 ↪logmel_KNN_correct, mel_KNN_correct, rms_KNN_correct, spec_KNN_correct,␣
 ↪MFCC_KNN_correct, cqt_KNN_correct], label="Incorrect")

plt.legend()
plt.xticks(range(len(feature_names_list)), feature_names_list)
plt.xlabel("Features")
plt.ylabel("Number of predictions")
plt.title("KNN")
plt.savefig("KNN.png")
plt.show()
```



```
[ ]: # SVM
# Calculate the number of correct predictions and incorrect predictions for␣
 ↪each feature
energy_SVM_correct = 0
energy_SVM_incorrect = 0
logmel_SVM_correct = 0
logmel_SVM_incorrect = 0
```

```
mel_SVM_correct = 0
mel_SVM_incorrect = 0
rms_SVM_correct = 0
rms_SVM_incorrect = 0
spec_SVM_correct = 0
spec_SVM_incorrect = 0
MFCC_SVM_correct = 0
MFCC_SVM_incorrect = 0
cqt_SVM_correct = 0
cqt_SVM_incorrect = 0

for i in range(len(SVM_concat)):
    if SVM_concat['energy'][i] == SVM_concat['y_test'][i]:
        energy_SVM_correct += 1
    else:
        energy_SVM_incorrect += 1
    if SVM_concat['logmel'][i] == SVM_concat['y_test'][i]:
        logmel_SVM_correct += 1
    else:
        logmel_SVM_incorrect += 1
    if SVM_concat['mel'][i] == SVM_concat['y_test'][i]:
        mel_SVM_correct += 1
    else:
        mel_SVM_incorrect += 1
    if SVM_concat['rms'][i] == SVM_concat['y_test'][i]:
        rms_SVM_correct += 1
    else:
        rms_SVM_incorrect += 1
    if SVM_concat['spec'][i] == SVM_concat['y_test'][i]:
        spec_SVM_correct += 1
    else:
        spec_SVM_incorrect += 1
    if SVM_concat['MFCC'][i] == SVM_concat['y_test'][i]:
        MFCC_SVM_correct += 1
    else:
        MFCC_SVM_incorrect += 1
    if SVM_concat['cqt'][i] == SVM_concat['y_test'][i]:
        cqt_SVM_correct += 1
    else:
        cqt_SVM_incorrect += 1

# Plot the diagram with the number of correct predictions and incorrect␣
 ↪predictions for each feature
plt.figure(figsize=(20,10))
plt.bar(feature_names_list, [energy_SVM_correct, logmel_SVM_correct,␣
 ↪mel_SVM_correct, rms_SVM_correct, spec_SVM_correct, MFCC_SVM_correct,␣
 ↪cqt_SVM_correct], label="Correct")
```

```
plt.bar(feature_names_list, [energy_SVM_incorrect, logmel_SVM_incorrect,␣
 ↪mel_SVM_incorrect, rms_SVM_incorrect, spec_SVM_incorrect,␣
 ↪MFCC_SVM_incorrect, cqt_SVM_incorrect], bottom=[energy_SVM_correct,␣
 ↪logmel_SVM_correct, mel_SVM_correct, rms_SVM_correct, spec_SVM_correct,␣
 ↪MFCC_SVM_correct, cqt_SVM_correct], label="Incorrect")
plt.xticks(range(len(feature_names_list)), feature_names_list)
plt.legend()
plt.xlabel("Features")
plt.ylabel("Number of predictions")
plt.title("SVM")
plt.savefig("SVM.png")
plt.show()
```



[ ]:
```
# export the csv file
KNN_concat.to_csv("KNN_concat.csv", index=False)
SVM_concat.to_csv("SVM_concat.csv", index=False)
```