Classifying Urban Sounds8K Dataset using MFCC and Machine Learning

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Overview :

For this example, we are going to classify Urban sounds dataset using MFCC and Machine Learning.

For this project we will use a dataset called Urbansound8K. The dataset contains 8732 sound excerpts (<=4s) of urban sounds from 10 classes, which are:

- Air Conditioner
- Car Horn
- Children Playing
- Dog bark
- Drilling
- Engine Idling
- Gun Shot
- Jackhammer
- Siren
- Street Music

The accompanying metadata contains a unique ID for each sound excerpt along with it's given class name. A sample of this dataset is included with the accompanying git repo and the full dataset can be downloaded from here.

Highlights :

- preparing the real life data for audiodatastore
- Standardize and normalize the digital signal data (Sample Rate, Bit-Depth, Number of Channel)
- Extract features using MFCC
- Train machine learning model using classification learner app
- deploy machine learning model to embedded devices or desktop application

Product Focus :

- MATLAB
- Audio Toobox
- Statistics and Machine Learning Toolbox
- Signal Processing Toolbox
- DSP System Toolbox

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Load Data - Audiodatastore

```
rng(1)
datafolder = "UrbanSound8K/structure";

ads = audioDatastore(datafolder, ...
    'IncludeSubfolders',true, ...
    'FileExtensions','.wav', ...
    'LabelSource','foldernames');

%Split Data
%Should not as low as 0.5, but it help me to accerelate the training
[trainDatastore, testDatastore] = splitEachLabel(ads,0.7,'randomized');

%Display the datastore and the number of speakers in the train datastore.
trainDatastore
```

```
trainDatastore =
  audioDatastore with properties:

                      Files: {
                             ' ...\UrbanSound8K\structure\Air Conditioner\100852-0-0-0.wav';
                             ' ...\UrbanSound8K\structure\Air Conditioner\100852-0-0-10.wav';
                             ' ...\UrbanSound8K\structure\Air Conditioner\100852-0-0-11.wav'
                              ... and 6109 more
                             }
                     Labels: [Air Conditioner; Air Conditioner; Air Conditioner ... and 6109 more categorical]
    AlternateFileSystemRoots: {}
              OutputDataType: 'double'
```

```
trainDatastoreCount = countEachLabel(trainDatastore)
```

trainDatastoreCount = 10×2 table

	Label	Count
1	Air Condi...	700
2	Car Horn	300
3	Children ...	700
4	Dog Bark	700
5	Drilling	700
6	Engine Id...	700
7	Gun Shot	262
8	Jackhammer	700
9	Siren	650
10	Street Mu...	700

```
%Display the datastore and the number of speakers in the test datastore.
testDatastore
```

```
testDatastore =
  audioDatastore with properties:

                      Files: {
                             ' ...\UrbanSound8K\structure\Air Conditioner\100852-0-0-1.wav';
```

```
                            ' ...\UrbanSound8K\structure\Air Conditioner\100852-0-0-20.wav';
                            ' ...\UrbanSound8K\structure\Air Conditioner\100852-0-0-27.wav'
                             ... and 2617 more
                            }
                    Labels: [Air Conditioner; Air Conditioner; Air Conditioner ... and 2617 more categorical]
AlternateFileSystemRoots: {}
          OutputDataType: 'double'
```

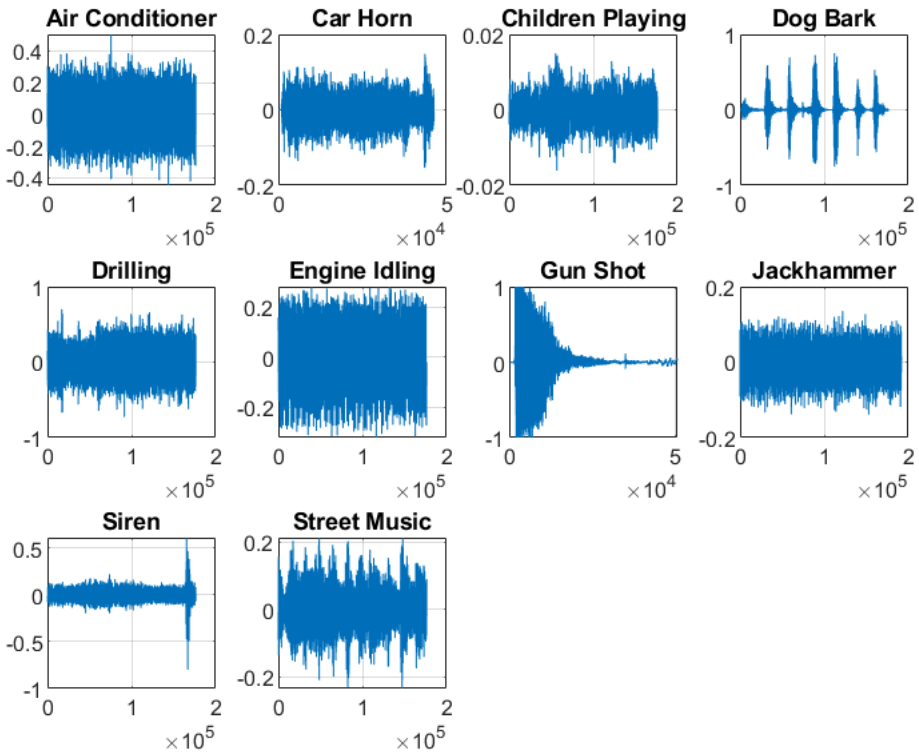
```
testDatastoreCount = countEachLabel(testDatastore)
```

testDatastoreCount = 10×2 table

	Label	Count
1	Air Condi...	300
2	Car Horn	129
3	Children ...	300
4	Dog Bark	300
5	Drilling	300
6	Engine Id...	300
7	Gun Shot	112
8	Jackhammer	300
9	Siren	279
10	Street Mu...	300

Visualize and Listen the Data (Wav. file)

```
figure()
datafolder = "UrbanSound8K/structure";
currentfolder = pwd;
cd(datafolder);
listdir=dir;
for i=3:1:length(listdir)
    cd(listdir(i).name)
    inside=dir;
    subplot(3,4,i-2);
    [y,fs]=audioread(inside(4).name);
    plot(y(:,:));
    soundsc(y(:,:),fs);
    grid on;
    title(listdir(i).name)
    drawnow;
    pause(5)
    cd(strcat(currentfolder,'\',datafolder));
end
```




```
cd(currentfolder);
```

Extract Features - MFCC

```
fs = 44100; %44.1khz
adstall = tall(trainDatastore);
% melspectrum, barkSpectrum, erbSpectrum
aFE = audioFeatureExtractor('SampleRate',44.1e3,'mfcc',true,'pitch',true, ...
    "Window",hamming(round(fs),"periodic"), ...
    "OverlapLength",fs*0.5);
specsTall = cellfun(@(x)extract(aFE,x),adstall,"UniformOutput",false);
specs = gather(specsTall);
```

```
Evaluating tall expression using the Parallel Pool 'local':
- Pass 1 of 1: Completed in 6 min 0 sec
Evaluation completed in 6 min 0 sec
```

Average the value of MFCC features within the same audio file :

```
for i = 1:1:length(specs)
    specs_new{i,1} = mean(specs{i});
end
```

Create a table for features and label them

```
x1 = cell2mat(specs_new(1));
```

```
specstable = array2table(x1);
specstable.Labels(1) = trainDatastore.Labels(1);
specstable.Files(1) = trainDatastore.Files(1);
for i=2:length(specs_new)
    x1 = cell2mat(specs_new(i));
    specstable_temp = array2table(x1);
    specstable_temp.Labels = trainDatastore.Labels(i);
    specstable_temp.Files = trainDatastore.Files(i);
    try
        specstable = [specstable;specstable_temp];
    end
end
```

Rank Features/Select Features

Using fscmrmr, for detail or other methods, please refer to https://www.mathworks.com/help/stats/feature-selection.html

```
[idx,scores] = fscmrmr(specstable(:,1:14),specstable(:,15));
%% Create a bar plot of the predictor importance scores.
bar(scores(idx))
xlabel('Predictor rank')
ylabel('Predictor importance score')
```

Use PCA to visualize the data before Machine Learning Training

```
[coeff,score,latent,tsquared,explained] = pca(specstable{:,1:11});
figure()
pareto(explained)
```

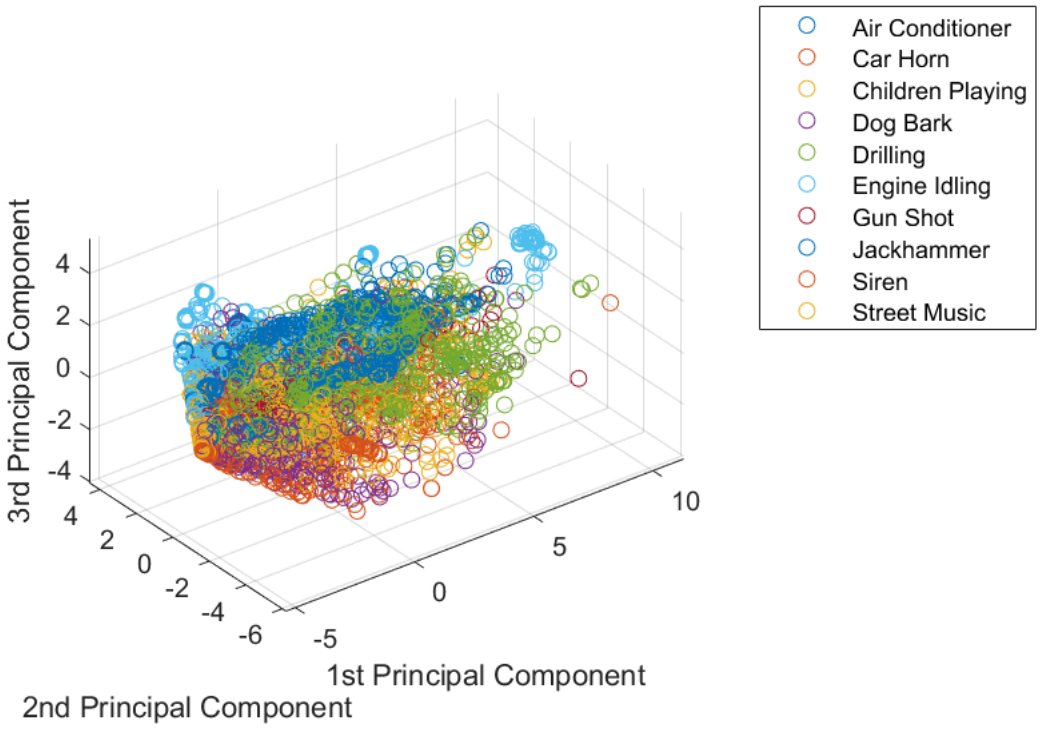
First 3 component represent :

```
sum(explained(1:3))
```

```
ans =
  90.868423703215072
```

```
Data_Class = categorical(["Air Conditioner","Car Horn","Children Playing","Dog Bark","Drilling"
figure()
for i =1:1:length(categories(specstable.Labels))
scatter3(score(specstable{:,15}==Data_Class(i),1),score(specstable{:,15}==Data_Class(i),2),scor
hold on
axis equal
end
legend(Data_Class)
xlabel('1st Principal Component')
ylabel('2nd Principal Component')
```

```
zlabel('3rd Principal Component')
grid on
hold off
```



Observation : Great, look at the graph, it represent 90% of the data, and it looks positive, with visual inspoection, we seem can draw line to separate classes.

Rearrage the name of column in table

```
specstable.Properties.VariableNames{1} = 'x1';
specstable.Properties.VariableNames{2} = 'x2';
specstable.Properties.VariableNames{3} = 'x3';
specstable.Properties.VariableNames{4} = 'x4';
specstable.Properties.VariableNames{5} = 'x5';
specstable.Properties.VariableNames{6} = 'x6';
specstable.Properties.VariableNames{7} = 'x7';
specstable.Properties.VariableNames{8} = 'x8';
specstable.Properties.VariableNames{9} = 'x9';
specstable.Properties.VariableNames{10} = 'x10';
specstable.Properties.VariableNames{11} = 'x11';
specstable.Properties.VariableNames{12} = 'x12';
specstable.Properties.VariableNames{13} = 'x13';
specstable.Properties.VariableNames{14} = 'x14';
```

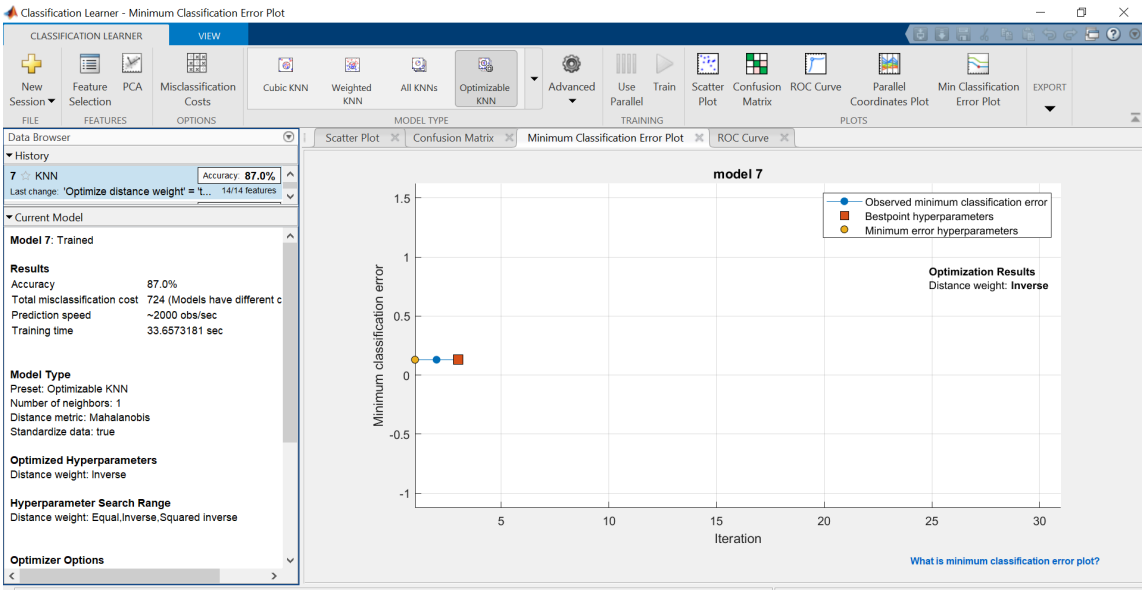
Machine Learning Training

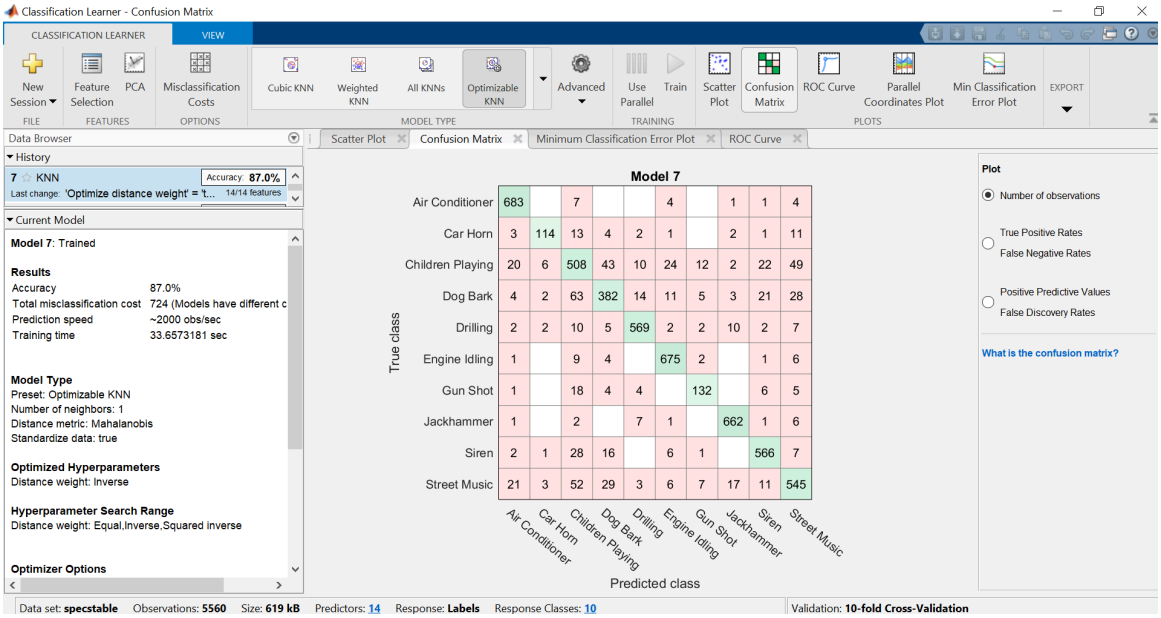
Using classification learner app to train the model and then export it back to workspace (Name the model as MFCCmodel)

- import specstable
- Train all models at first run
- Select the best model to do bayesian optimization
- Select the best model to impose higher cost matrix to certain misclassication classes.
- Export the model back to workspace

```
classificationLearner
```

Results :





save model

```
save mymodel2.mat trainedModel
```

Verify with testing dataset

- Extract features from testing datset

```
fs = 44100; %44.1khz
adstall_test = tall(testDatastore);
% melspectrum, barkSpectrum, erbSpectrum
aFE = audioFeatureExtractor('SampleRate',44.1e3,'mfcc',true,'pitch',true, ...
    "Window",hamming(round(fs),"periodic"), ...
    "OverlapLength",round(0.5*fs));
specsTall_test = cellfun(@(x)extract(aFE,x),adstall_test,"UniformOutput",false);
specstest = gather(specsTall_test);
```

```
Evaluating tall expression using the Parallel Pool 'local':
- Pass 1 of 1: Completed in 3 min 3 sec
Evaluation completed in 3 min 3 sec
```

```
for i = 1:1:length(specstest)
    specs_new_test{i,1} = nanmean(specstest{i});
end

x1 = cell2mat(specs_new_test(1));
specstabletest = array2table(x1);
specstabletest.Labels(1) = testDatastore.Labels(1);
specstabletest.Files(1) = testDatastore.Files(1);
for i=2:length(specs_new_test)
    x1 = cell2mat(specs_new_test(i));
    specstable_temp_test = array2table(x1);
    specstable_temp_test.Labels = testDatastore.Labels(i);
    specstable_temp_test.Files = testDatastore.Files(i);
    try
        specstabletest = [specstabletest;specstable_temp_test];
    end
end
```

```
specstabletest.Properties.VariableNames{1} = 'x1';
specstabletest.Properties.VariableNames{2} = 'x2';
specstabletest.Properties.VariableNames{3} = 'x3';
specstabletest.Properties.VariableNames{4} = 'x4';
specstabletest.Properties.VariableNames{5} = 'x5';
specstabletest.Properties.VariableNames{6} = 'x6';
specstabletest.Properties.VariableNames{7} = 'x7';
specstabletest.Properties.VariableNames{8} = 'x8';
specstabletest.Properties.VariableNames{9} = 'x9';
specstabletest.Properties.VariableNames{10} = 'x10';
specstabletest.Properties.VariableNames{11} = 'x11';
```

```
specstabletest.Properties.VariableNames{12} = 'x12';
specstabletest.Properties.VariableNames{13} = 'x13';
specstabletest.Properties.VariableNames{14} = 'x14';
```

- Prediction with testing dataset

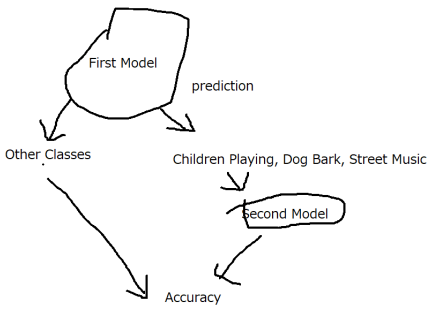
```
[predictionoutcome,scores]=trainedModel.predictFcn(specstabletest);
fig = figure;
cm = confusionchart(string(predictionoutcome),string(specstabletest.Labels),'RowSummary','row-r
```

```
accuracy=sum(string(predictionoutcome)==string(specstabletest.Labels))/length(specstabletest.La
```

```
accuracy =
   0.835496023440770
```

Further Improvement with aggregated model

- I notice missclassification are mainly happened between children playing, dog bark and and street music. Now i'm going to implement aggragted approach, which if the outcome from our model is children playing/dog bark/street music, then they will be classified again with another model (the model is only trained to classify this 3 classification).
- Add some time-domain features for second model



extract train data (classes = children playing, dog bark and street music)

```
clearvars ShapeFactor Kurtosis Skew PeakValue CrestFactor ImpulseFactor ClearanceFactor
children=specstable(strcmp(string(specstable.Labels),'Children Playing'),:);
dog=specstable(strcmp(string(specstable.Labels),'Dog Bark'),:);
music=specstable(strcmp(string(specstable.Labels),'Street Music'),:);
gun=specstable(strcmp(string(specstable.Labels),'Gun Shot'),:);
predict2table = [children;dog;music;gun];
for i = 1:1:height(predict2table)
    New_Signal = audioread(predict2table.Files{i});
    % Shape factor
    RMS = rms(New_Signal); %Root mean square
```

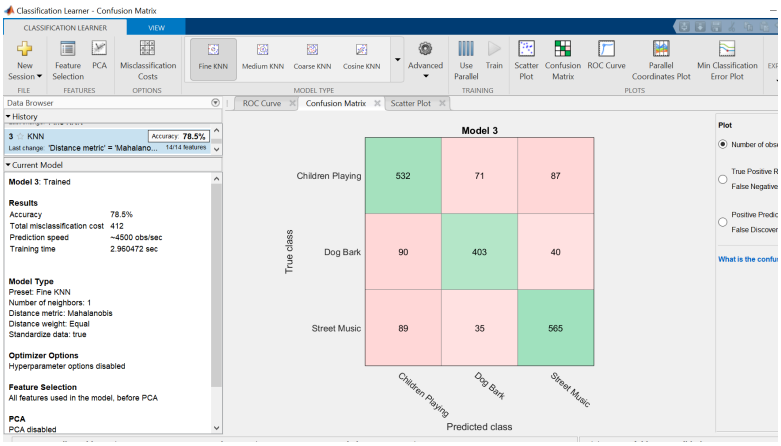
```
    ShapeFactor(i) = RMS/mean(abs(New_Signal)); %shape factor (RMS/Mean of absolute value)
    %Higher order statistic
    Kurtosis(i) = kurtosis(New_Signal);%Kurtois
    Skew(i)= skewness(New_Signal);%Skweness
    %Impulsive Metrics
    PeakValue(i) = max(New_Signal);%Peak value
    CrestFactor(i) = peak2rms(New_Signal);%Crest Factor %Ratio of absolute value to rms
    ImpulseFactor(i) = PeakValue(i)/mean(abs(New_Signal));%Impulse Factor %Ratio of maximum abs
    ClearanceFactor(i) = PeakValue(i)/(mean(sqrt(abs((New_Signal)))))^2;%Clearance Factor %Rati
end
```

```
predict2table.ShapeFactor = ShapeFactor';
predict2table.Kurtosis = Kurtosis';
predict2table.Skew = Skew';
predict2table.PeakValue = PeakValue';
predict2table.CrestFactor = CrestFactor';
predict2table.ImpulseFactor = ImpulseFactor';
predict2table.ClearanceFactor = ClearanceFactor';
```

Train second model

```
classificationLearner
```

Result :



save model

```
save mymodel3.mat trainedModel7
```

```
clearvars ShapeFactor Kurtosis Skew PeakValue CrestFactor ImpulseFactor ClearanceFactor
for i = 1:1:height(specstabletest)
    New_Signal = audioread(specstabletest.Files{i});
    % Shape factor
    RMS = rms(New_Signal); %Root mean square
    ShapeFactor(i) = RMS/mean(abs(New_Signal)); %shape factor (RMS/Mean of absolute value)
    %Higher order statistic
```

```
    Kurtosis(i) = kurtosis(New_Signal);%Kurtois
    Skew(i)= skewness(New_Signal);%Skweness
    %Impulsive Metrics
    PeakValue(i) = max(New_Signal);%Peak value
    CrestFactor(i) = peak2rms(New_Signal);%Crest Factor %Ratio of absolute value to rms
    ImpulseFactor(i) = PeakValue(i)/mean(abs(New_Signal));%Impulse Factor %Ratio of maximum abs
    ClearanceFactor(i) = PeakValue(i)/(mean(sqrt(abs((New_Signal)))))^2;%Clearance Factor %Rati
end
```

```
specstabletest.ShapeFactor = ShapeFactor';
specstabletest.Kurtosis = Kurtosis';
specstabletest.Skew = Skew';
specstabletest.PeakValue = PeakValue';
specstabletest.CrestFactor = CrestFactor';
specstabletest.ImpulseFactor = ImpulseFactor';
specstabletest.ClearanceFactor = ClearanceFactor';
```

verify the accuracy with testing dataset (go through 2 model)

```
[predictionoutcome,scores]=trainedModel.predictFcn(specstabletest);
for i = 1:1:length(predictionoutcome)
    if strcmp(string(predictionoutcome(i)),"Children Playing") || strcmp(string(predictionoutcc
        predictionoutcome(i)=trainedModel7.predictFcn(specstabletest(i,:));
    end
end
fig = figure;
cm = confusionchart(string(predictionoutcome),string(specstabletest.Labels),'RowSummary','row-r
```

```
accuracy=sum(string(predictionoutcome)==string(specstabletest.Labels))/length(specstabletest.La
```

```
accuracy =
   0.851402260359983
```