Speech Recognition of Spoken Digits

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Lecture Information

Sensor Signal Processing

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What did we learn?

Signal Processing and Analysis

Feature Computation

Cluster Analysis

Dimensionality Reduction Techniques

What did we learn?

Data Visualisation & Analysis

Classification Techniques

Sensor Fusion

Systematic Design of Sensor Systems

Sensor Signal Processing Project

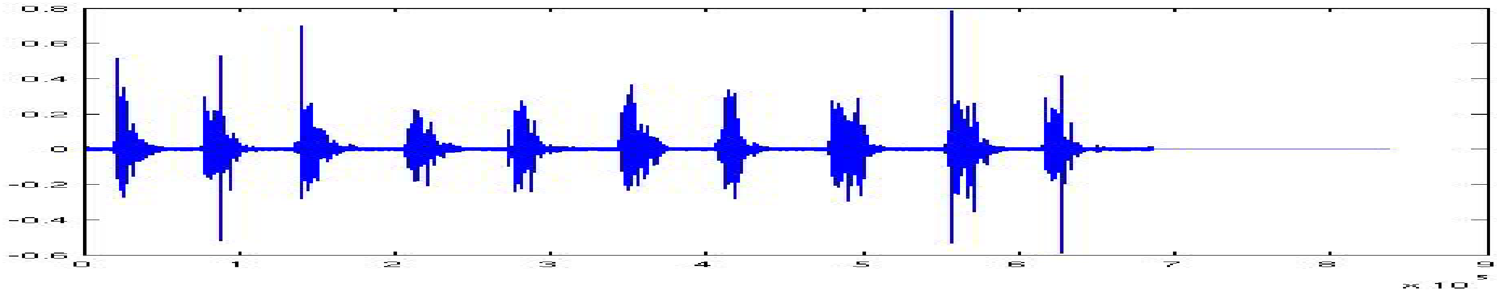
Case study: Speech Recognition of Spoken Digits

- General task for a project:
  - Design and implementation of a recognition system for either image or audio data with the programs Matlab and/or QuickCog
    - Recording / taking of training data
    - Preprocessing to enhance input signals for a ensuing feature computation
    - Selection and computation of suitable features
    - Classification of training and test data
  - Here:
    - Recording of spoken digits with a microphone
    - Implementation of a digit recognition system with Matlab

Training Data

- German Digits (0 to 9), only one speaker
- 10 audio recordings per digit in one wav-file
  (audio recording with 22050 Hz, mono, 16bit)

  -> approximately 8*10^5 sampling points per wav-file



Example for digit 3

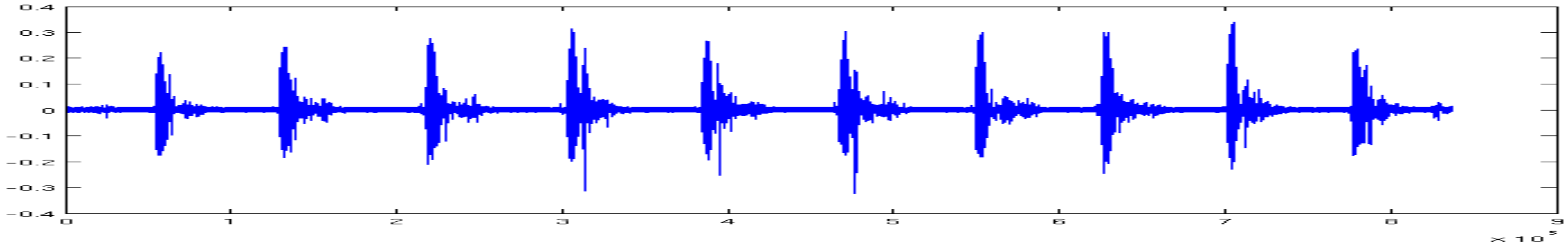
Preprocessing of the Audio Signal

Preprocessing of the audio signal (training and test data) completely in Matlab. Usage of Matlab and own functions:

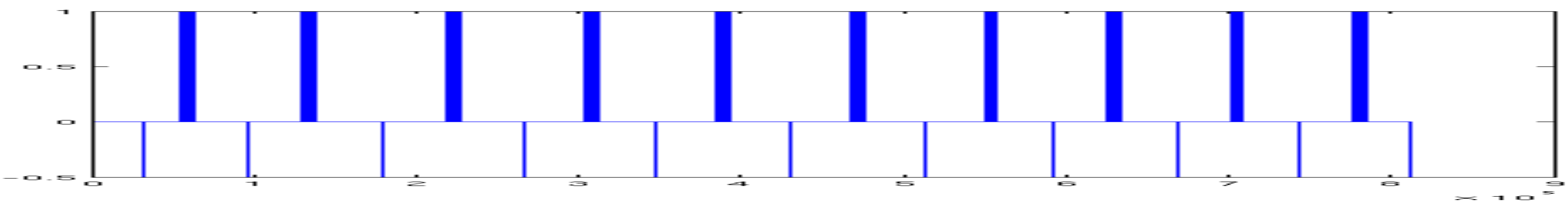
- Adjustment of the y-position of the signal depending on it‘s offset (Offset correction)
  - Signal = Signal – mean value (Signal).
- Noise reduction
  - Noise reduction via low pass filtering
    (the frequency response depends on the noise).
- Separation of the complete audio signal (a series of digits) to smaller audio signals. After the separation a contiguous signal contains only one digit.

Separation of the Audio Signal

- Input signal with noise reduction and offset correction (digit 1).

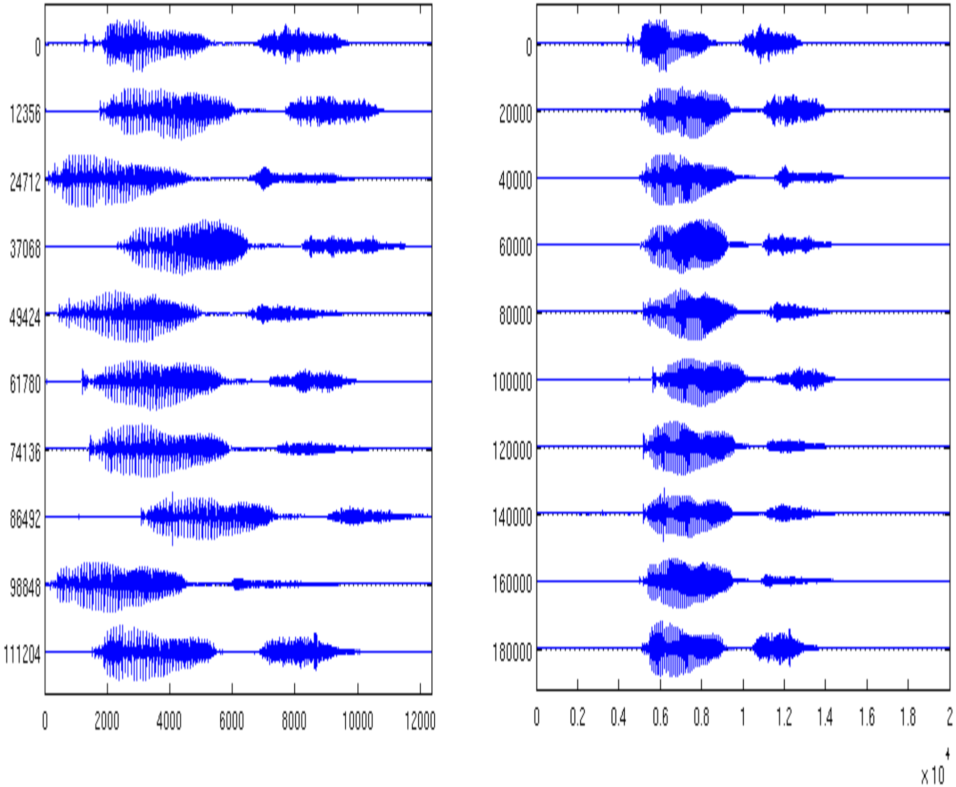


- Extreme values (fixed threshold, bars > 0) and resulting cutting positions (mean position between the extreme values of two different digits, bars < 0).



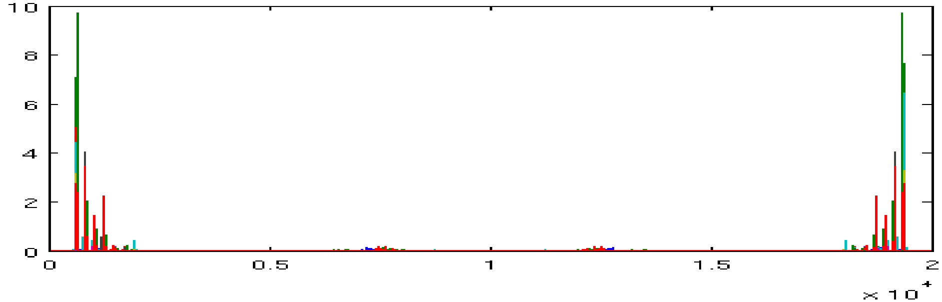
Separation of the Audio Signal

- Cutting of the audio signal in regions which contain only one digit.
- Amplitude scaling (for each digit separately) to the codomain [-1, 1].
- Positioning of each digit using correlation and / or center point adjustment.
- Each signal now consists of 20000 sampling points.



Feature Computation (1)

- Frequency analysis of the audio signal of one digit via Fourier transformation.
- Sub sampling of the signal to reduce the number of the sampling points (usage of low pass filters)
- Example for ten times the digit 1



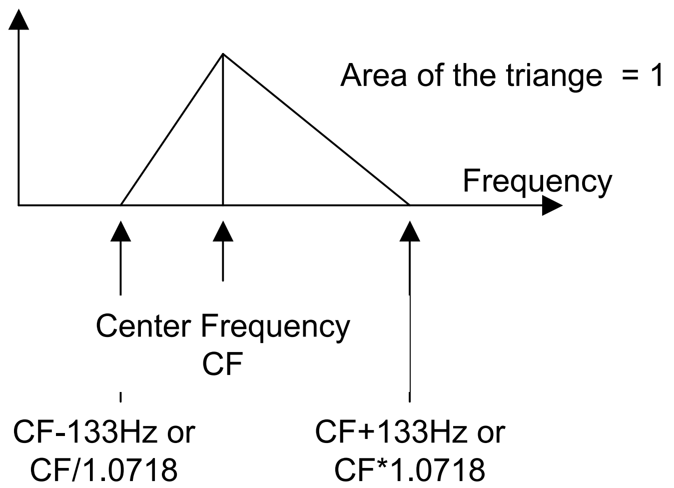
- In ensuing tests, this feature wasn't sufficient for a suitable discrimination between the ten different digits.

Feature Computation (2)

- Mel Frequency Cepstral Coefficients (MFCC)
  - Usage of the ‚Auditory Toolbox: A Matlab Toolbox for Auditory Modeling Work' for the MFCC Computation:
  - Windowing of the input signal (here: with a hamming window, usually sampling windows every 10 msec)
  - Discrete Fourier transformation of each window
  - Logarithm (base 10) of the Fourier coefficients
  - Mapping of the results to the „Mel-Scale" using triangle filters
  - Usage of the first 13 MFCC parameter curves

Feature Computation (2)

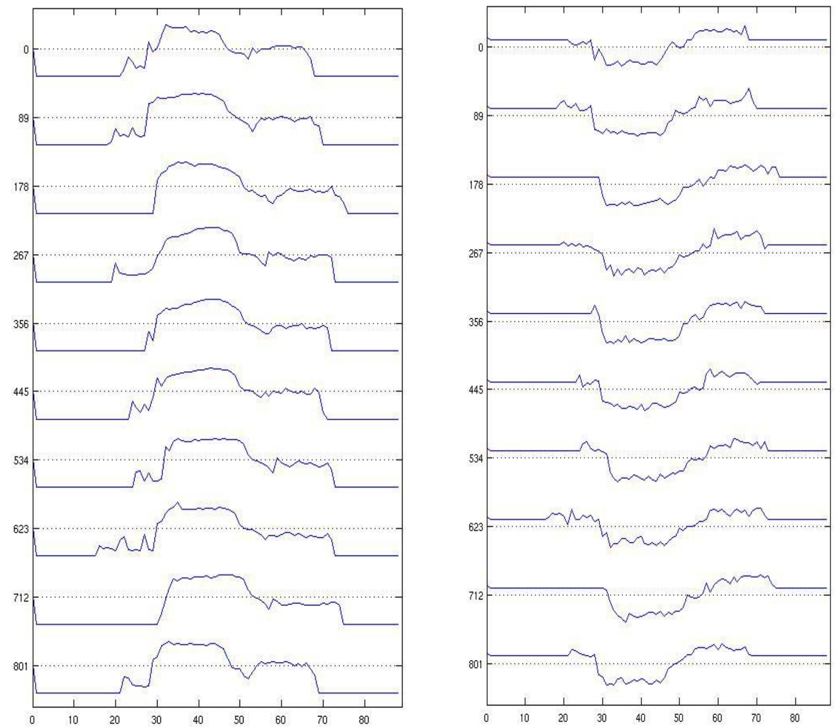
- Filter bank of triangle filters:



The filter bank is constructed using 13 linearly-spaced filters with a distance of 133.33 Hz between the center frequencies followed by 27 log-spaced filters (separated by a factor of 1.0711703 in frequency).

Training and Classification with Matlab

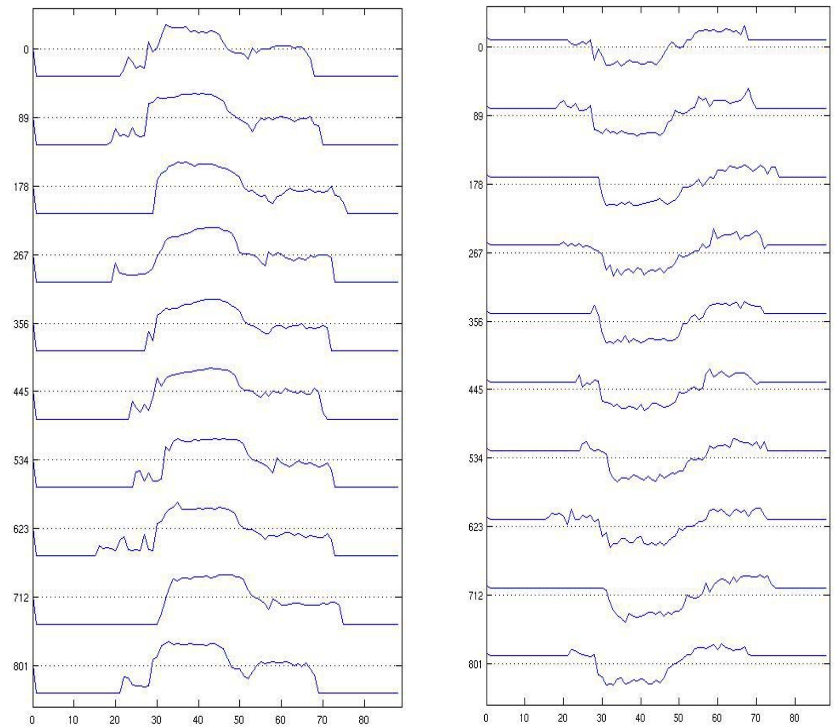
- Method:
  - Usage of the first 13 MFCC parameter curves of the training data in comparison to the test data parameter curves
  - Each MFCC parameter curve contains 89 values (size audio signal (one digit): 20000 sampling points, sampling rate audio signal: 22050Hz, frame rate hamming window: 100Hz)
  - Scaling of the parameter curves to the codomain [0,1]



MFCC 1 (left), MFCC 5 (right) for the ten audio signals of the digit 1

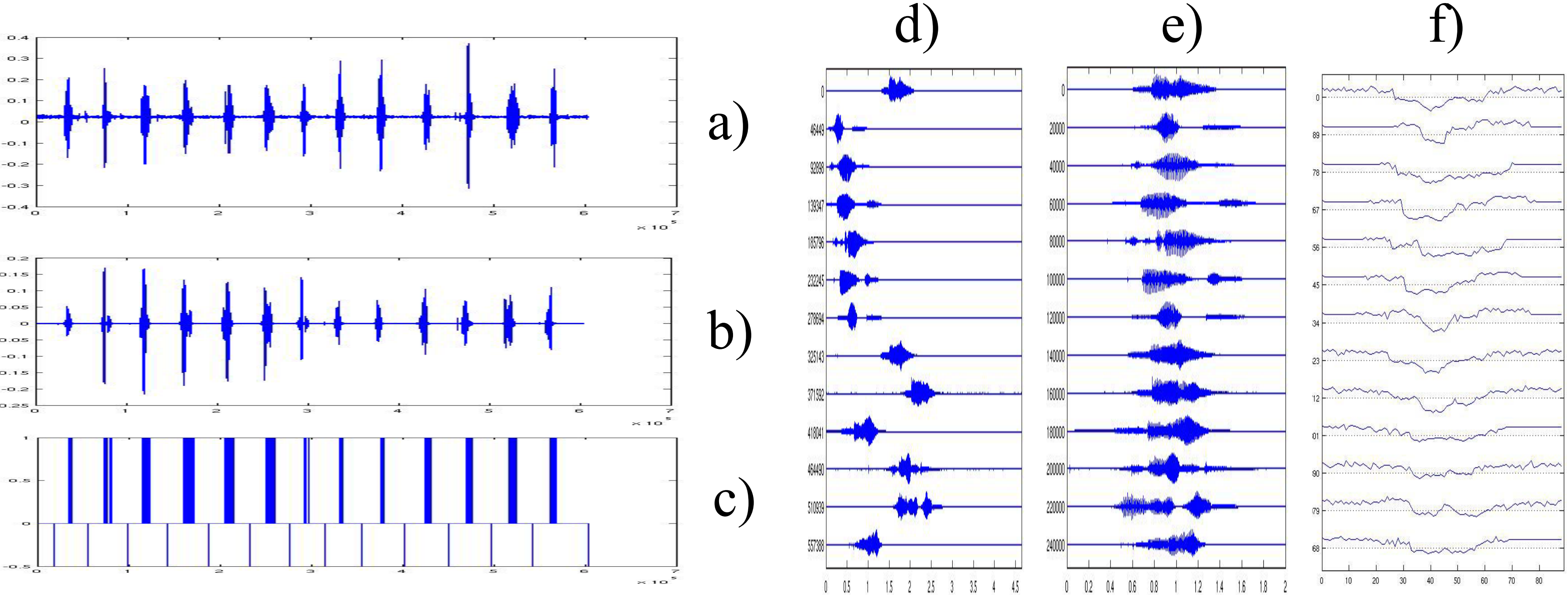
Training and Classification with Matlab

- Method:
  - Computation of the correlation (of the 13 MFCC parameter curves) between training data and test data.
  - The maximal correlation of all MFCC parameter curves is added up for each training sample.
  - The training sample with the highest sum (maximal correlation) sets the affiliation of a test digit.



MFCC 1 (left), MFCC 5 (right) for the ten audio signals of the digit 1

Example: Phone Number



a) No.: 0631/316004574, b) Offset correction and lowpass filtering, c) Extremal values and resulting cutting positions, d) Separated Digits, e) Positioning, f) MFCC 5

-> Recognition rate: 100% (using 13 MFCC parameter curves)

Test results

- As a result of the classification method all training samples are classified correctly.
- In the following table, the results of the classification for different test audio signals are shown, using only one MFCC parameter curve at a time as well as the combined results for all 13 parameter curves.
- Displayed are the recognition rates using the normalizes MFCC parameter curves. Wrong classification is highlighted in red color.

Test results (1)

MFCC (scaled: [0,1])	A: 5 times each digit _1 , 2, 3, 4, 5, 6, 7, 8, 9, 0		B (like A, different micro, more noise):	
MFCC 1:	5/5, 5/5, 1/5, 3/5, 5/5, 5/5, 4/5 ,5/5, 5/5, 3/5	41/50	5/5, 5/5, 1/5, 3/5, 5/5, 5/5, 4/5 ,5/5, 5/5, 3/5	41/50
MFCC 2:	5/5, 5/5, 1/5, 4/5, 5/5, 2/5, 2/5 ,5/5, 5/5, 5/5	39/50	5/5, 4/5, 4/5, 1/5, 2/5, 2/5, 0/5 ,5/5, 2/5, 4/5	20/50
MFCC 3:	5/5, 5/5, 4/5, 1/5, 3/5, 5/5, 5/5 ,5/5, 5/5, 5/5	43/50	5/5, 5/5, 5/5, 0/5, 2/5, 4/5, 2/5 ,5/5, 5/5, 1/5	34/50
MFCC 4:	5/5, 5/5, 5/5, 4/5, 4/5, 4/5, 3/5 ,5/5, 5/5, 5/5	45/50	5/5, 5/5, 5/5, 1/5, 2/5, 4/5, 1/5 ,5/5, 5/5, 1/5	34/50
MFCC 5:	5/5, 5/5, 5/5, 3/5, 5/5, 5/5, 5/5 ,5/5, 5/5, 5/5	48/50	5/5, 5/5, 5/5, 0/5, 3/5, 4/5, 1/5 ,4/5, 4/5, 2/5	33/50
MFCC 6:	5/5, 3/5, 2/5, 4/5, 5/5, 3/5, 5/5 ,5/5, 5/5, 3/5	40/50	5/5, 2/5, 4/5, 3/5, 3/5, 5/5, 3/5 ,5/5, 4/5, 0/5	34/50
MFCC 7:	5/5, 2/5, 0/5, 4/5, 3/5, 5/5, 3/5 ,5/5, 5/5, 5/5	37/50	5/5, 5/5, 2/5, 1/5, 0/5, 5/5, 1/5 ,1/5, 1/5, 0/5	22/50
MFCC 8:	5/5, 0/5, 5/5, 3/5, 4/5, 4/5, 3/5 ,5/5, 5/5, 2/5	36/50	5/5, 0/5, 4/5, 0/5, 1/5, 4/5, 1/5 ,1/5, 5/5, 2/5	23/50
MFCC 9:	5/5, 4/5, 2/5, 1/5, 5/5, 5/5, 2/5 ,5/5, 5/5, 4/5	38/50	5/5, 3/5, 0/5, 0/5, 2/5, 5/5, 0/5 ,0/5, 5/5, 2/5	22/50
MFCC 10:	3/5, 0/5, 4/5, 4/5, 0/5, 3/5, 1/5 ,5/5, 5/5, 5/5	30/50	3/5, 5/5, 3/5, 0/5, 0/5, 0/5, 0/5 ,5/5, 2/5, 3/5	21/50
MFCC 11:	5/5, 4/5, 5/5, 3/5, 0/5, 4/5, 1/5 ,2/5, 4/5, 4/5	32/50	5/5, 5/5, 1/5, 2/5, 0/5, 0/5, 0/5 ,1/5, 5/5, 0/5	19/50
MFCC 12:	1/5, 1/5, 5/5, 4/5, 2/5, 2/5, 4/5 ,5/5, 5/5, 5/5	34/50	1/5, 2/5, 4/5, 1/5, 1/5, 4/5, 3/5 ,5/5, 4/5, 2/5	27/50
MFCC 13:	2/5, 1/5, 2/5, 1/5, 1/5, 3/5, 4/5 ,5/5, 1/5, 2/5	22/50	2/5, 1/5, 2/5, 0/5, 0/5, 1/5, 0/5 ,5/5, 5/5, 0/5	16/50
All:	5/5, 5/5, 5/5, 5/5, 5/5, 5/5, 5/5 ,5/5, 5/5, 5/5	50/50	5/5, 5/5, 5/5, 4/5, 3/5, 5/5, 3/5 ,5/5, 5/5, 4/5	44/50

Test results (2)

	C: Phone Number: 0049 / 613316004574	D: (like C, different micro, more noise): 0049 / 613316004574	E: a series of digits: 1234567890
MFCC 5: (best results when using only one MFCC)	5539 / 631316774574	0039 / 631316004574	1233567899
All :	0049 / 631316004574	0049 / 631316004574	1234567899
	F: Pizza Service 1 (Joey's): 0631 / 10865	G: Pizza Service 2: 004963110865	H: Pizza Service 3: 10865
MFCC 5:	0641 / 10865	6023 / 62116065	10165
All :	0631 / 10865	0049 / 63110865	10865
	I: Digits 1-5 (soft-spoken)	J: Digits 1-5 (loud)	K: Phone Number 2: 0180 / 333 999
MFCC 5:	62345	12025	9186 233 999
All :	12345	12345	9180 333 999
	Other Female: 1739	Other Female: 3456	Other Male: 3578
All:	1730	3436	3662

Conclusions

- Results:
  - Suitable training of a recognition system that recognizes spoken digits from one speaker.
  - More than one MFCC parameter curve is needed for the classification.
  - Pattern Matching via correlation needs a lot of time.
    (Training: 100 digits -> 1 min, Testing: 10 digits -> 2 min)
  - No suitable digit recognition for different speakers.

- Further problems:
  - Scaling of the length of a spoken digit is difficult to implement.

Questions

???

Matlab Functions

One example function for training and testing with Matlab:

function SpeechRecognitionExp ()

- S1 = loadTrainingData1(0); // load training data (here: 10 wav files (->100 digits))
- T1 = loadTestData1(0); // load test data (here: 10 wav files (->50 digits))

- PlotParam = 0; // 1: plot results (filtered signal cut signal, mfcc parameter, …)
- FilterParam = [800, 0.005, 0.99999]; // Filter size and frequencies for a band pass filter
- CutsParam = [0.1, 0.05, 10000]; // Thresholds for the separation of the digits, minimum distance between two digits (in sampling points)
- MFCCParam = 0; // 0: all MFCC parameters, >0 only one MFCC parameter
- NormalizeParam = 1; // 1: scale MFCC parameters to [0,1]

- [MFCCSignal, FilterParamTrain, CutsParamTrain] = SpeechRecogTrain(S1, MFCCParam, PlotParam, FilterParam, CutsParam);
- SpeechRecogTest(MFCCSignal, T1, MFCCParam, NormalizeParam, PlotParam, FilterParamTrain, CutsParamTrain);