EXTRACTION OF ROBUST FEATURES BY COMBINING NOISE REDUCTION AND FDLP FOR THE RECOGNITION OF NOISY SPEECH SIGNALS IN HANDS-FREE MODE

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Speech Input in Hands-free Mode

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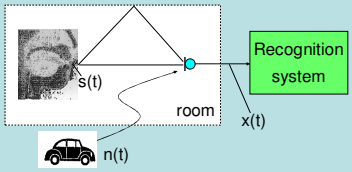


Two major effects

- Additive noise
- Reverberation

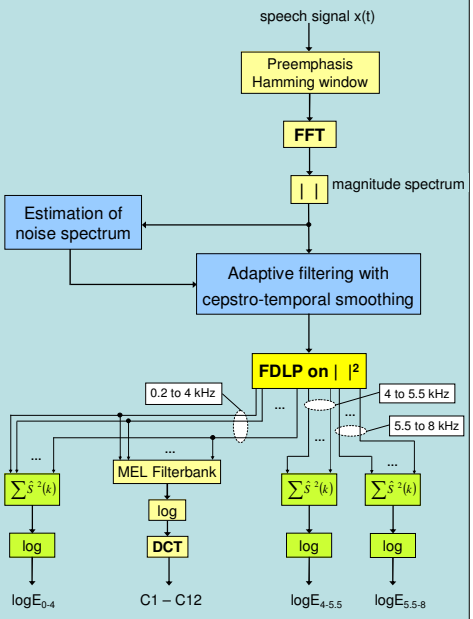
$$x(t) = s(t) * h_{rir}(t) + n(t)$$

Effects on acoustic features

- Stationary noise can be treated as additive component in the short-term spectrum
  ➔ Adaptive filtering in the spectral domain
- Reverberation causes a modification of the energy contour in each subband (can be roughly modeled as low pass filtering, Houtgast&Steeneken)
  ➔ Processing of subband energy contours (FDLP)

Robust Feature Extraction

Modified cepstral analysis scheme:

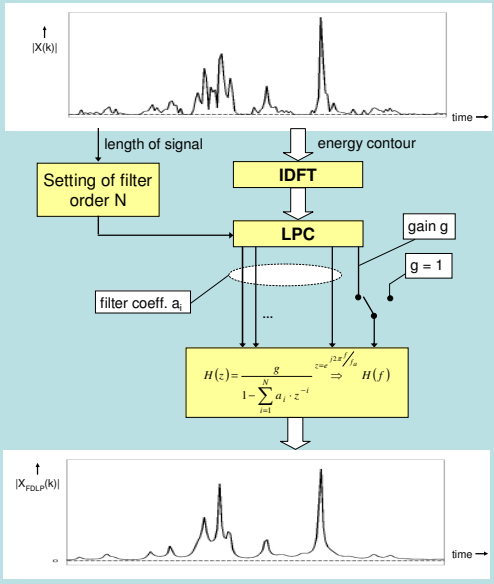


- Adaptive filtering in the DFT magnitude spectral domain
  - Cepstro temporal smoothing of filter characteristics (C. Breithaupt, T. Gerkmann, R. Martin) to reduce „musical tones“
- Frequency Domain Linear Prediction (FDLP) on contours of spectral magnitude in each DFT bin
- Calculation of 12 cepstral coefficients C1 to C12 and the logarithmic energy $\log E_{0\text{-}4}$ in the frequency range from 200 Hz up to 4 kHz
- For higher sampling frequencies of 11 or 16 kHz one or two additional energy parameters $\log E_{4\text{-}5.5}$ and $\log E_{5.5\text{-}8}$ are calculated.
- Adding Delta and Delta-Delta coefficients a feature vector consists of 39, 42 or 45 components dependent on the sampling frequency.
  - Training HMM parameters on the features of 16 kHz data, the HMMs can also be used for the recognition of signals at lower frequencies.

Frequency Domain Linear Prediction (FDLP)

2

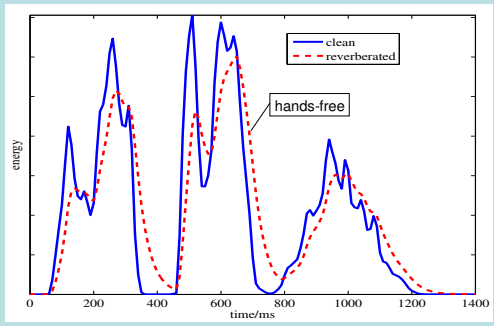
- Processing of energy contours in spectral subbands (here: temporal sequence of magnitude components in each DFT bin)



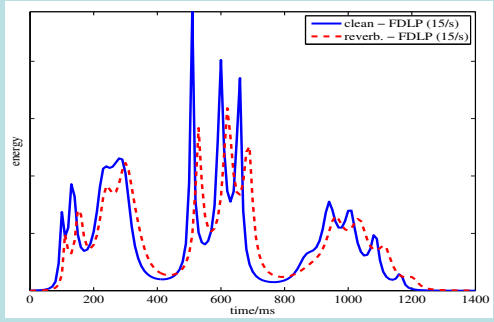
- The energy contour is considered as the filter characteristic of an all-pole model.
- FDLP leads to a smoothing of the energy contour in case of a low filter order.

Example

- The figure below contains the energy contours of a clean signal and a second hands-free version:



- Processing both contours by FDLP with a filter order of 15 per second:



- The two contours after FDLP processing look similar.
- Indication that this processing step should create acoustic features that are fairly robust against the effects of reverberation.
- FDLP has been applied with a filter of order 30 per second and gain normalization in all listed recognition experiments. ➔ NR_FDLP30 in figures and tables

Recognition Experiments

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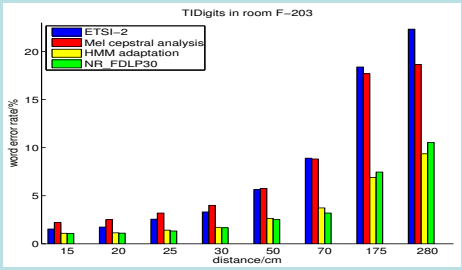
1. **Recognition** of several versions of the **TIDigits** containing the effect of a hands-free recording in an office at a varying distance between speaker and microphone.



- Comparison with an alternative HMM adaptation scheme and with ETSI's robust front-end

2. Reverb Challenge Task

- Word error rates for the evaluation test sets:

analysis	SimData						
	Room1		Room2		Room3		Average
	Near	Far	Near	Far	Near	Far	
MFCC_0_D_A_Z	18.06	25.38	42.98	82.20	53.54	88.04	**51.68 %**
NR_FDLP30	21.08	25.50	27.72	58.76	31.72	69.73	**39.07 %**

analysis	RealData		
	Room1		Average
	Near	Far	
MFCC_0_D_A_Z	89.72	87.34	**88.53 %**
NR_FDLP30	75.53	72.48	**74.00 %**

- Considerable overall improvement
- Small degradation in case of clean speech or signals with low reverberation

3. Noisy WSJCAM0 data

- Only a small amount of stationary noise at a SNR of 20 dB is taken into account within the Reverb Challenge task. In a lot of applications noise signals will occur in the background at a lower SNR.
- Two further versions of the development test set have been created by adding car noise respectively interior noise to the 742 utterances at a SNR of 10 dB.

analysis	interior noise (SNR=10dB)			car noise (SNR=10dB)		
	set r1	set r2	set r3	set r1	set r2	set r3
MFCC_0_D_A_Z	44.5 %	45.5 %	44.4 %	40.8 %	41.9 %	39.6 %
NR_FDLP30	31.5 %	32.7 %	30.5 %	32.6 %	35.0 %	33.1 %

- High word error rates due to the noise
- Considerable improvements by applying the adaptive filtering technique

Discussion

- In most applications with a hands-free speech input additive noise and reverberation will occur together.
- Which one is the dominant effect?
- The author could assess within other experiments that noise becomes dominant at low SNR.

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The Center For Language and Speech Processing
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