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Robust Spectral Representation Using Group Delay Function and Stabilized Weighted Linear Prediction for Additive Noise Degradations

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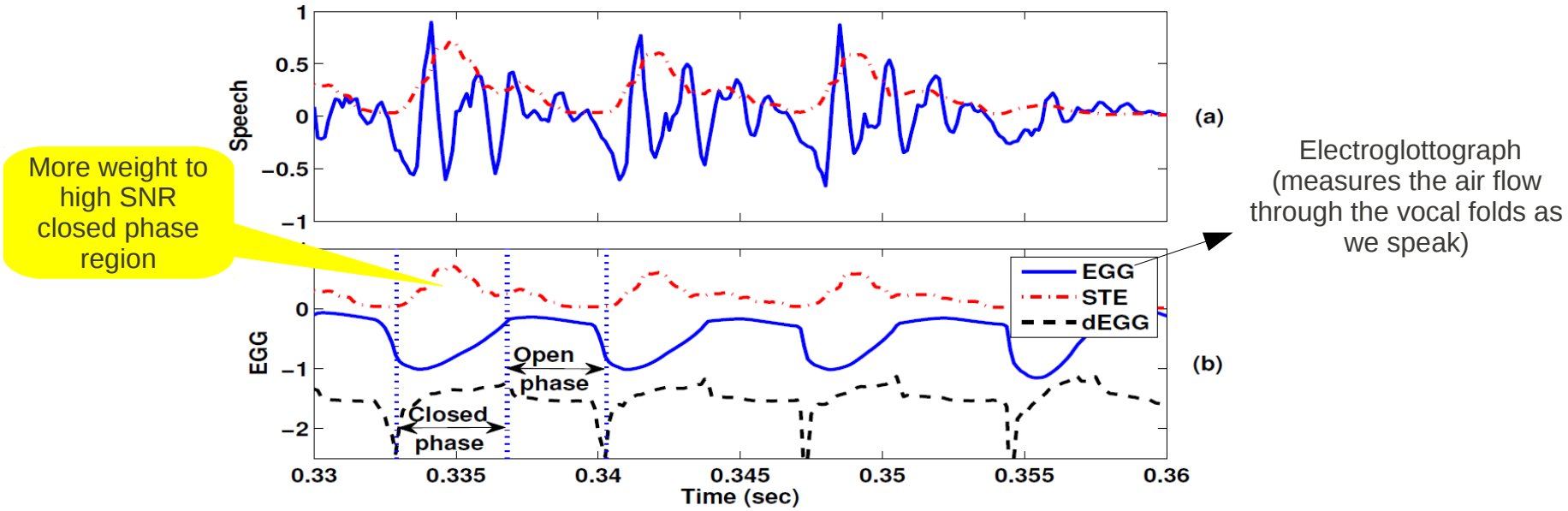
Outline

- Weighted linear prediction (WLP)
  - Stabilized weighted linear prediction (SWLP)
- Group delay (GD) of an all-pole model
- SWLP-GD spectrum
- Robustness of SWLP-GD spectrum
- Speaker recognition experiments
- Conclusions

Weighted linear prediction

- Idea: give more importance/weight to reduce prediction errors in the close phase region of the glottal cycle
- Provides better estimates of the vocal tract
- Noise robust as the focus is now on high SNR region
- Short time energy (STE) is one such weight function
  - [*Ma et al., Speech Comm. 1993*]
- Stabilized WLP (SWLP) ensures stability of the estimated poles
  - [*Magi et al., Speech Comm. 2008*]

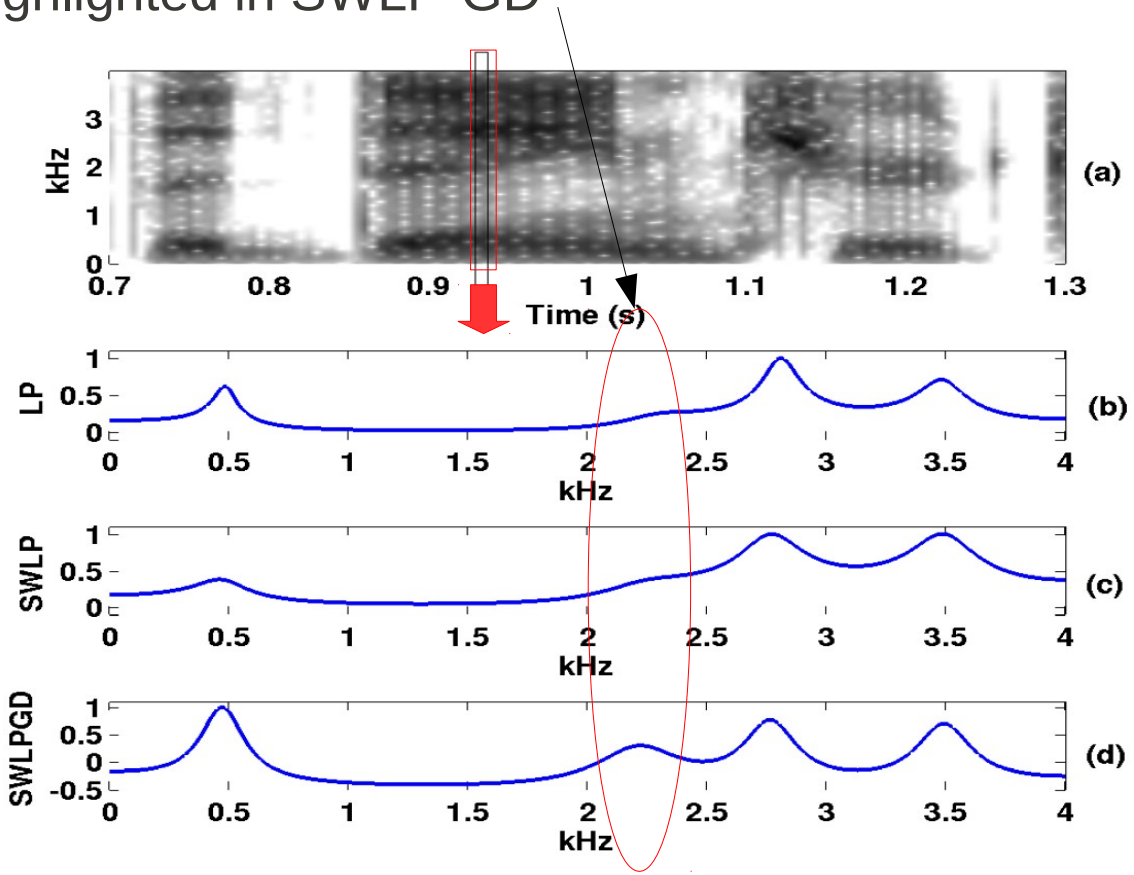


Group delay of an all-pole system

- Group delay (GD) function – negative derivative of phase spectrum
- GD function is additive in nature (w.r.t. individual resonances) as against multiplicative magnitude spectrum
- Formant peaks are better resolved
- Formant peaks are better highlighted even under degradations
- Can be computed from the inverse filter impulse response
- Avoids phase unwrapping

SWLP-GD spectrum

- Computed as the group delay function of the SWLP spectrum
- SWLP tends to smooth the spectrum due to weighting
- SWLP-GD brings back the formant resolution
- Weak formants better highlighted in SWLP-GD



Robustness of SWLP-GD

- Objective measure #1
  - average log spectral distortion (LSD)
  - LSD between normalized spectra from clean and degraded speech
  - Spectra normalized to unit energy
- Data
  - VTR database (192 utterances, 24 speakers, 8 female & 16 male)
  - Degradations from NOISEX database
- Observations
  - STRAIGHT marginally better than LP
  - SWLP better than STRAIGHT
  - SWLP-GD improves upon SWLP and performs the best

$$d_{LS} = \frac{2}{K} \sum_{k=0}^{K/2} |20 \log_{10}(H[k]) - 20 \log_{10}(\hat{H}[k])|$$

SNR (dB)	SPECTRUM TYPE				
	SWLP-GD	SWLP	LP	DFT	STRT
BABBLE					
10	**1.1**	1.7	2.8	3.5	2.9
5	**1.5**	2.5	4.0	4.6	3.9
0	**1.9**	3.3	5.2	5.7	5.0
-5	**2.2**	4.2	6.3	6.7	6.0
FACTORY					
10	**1.4**	2.3	3.8	4.5	3.6
5	**1.7**	3.2	5.2	5.8	4.9
0	**2.0**	4.2	6.5	6.8	6.1
-5	**2.3**	5.0	7.6	7.7	7.1
VOLVO					
10	**0.2**	0.2	0.3	1.1	0.6
5	**0.4**	0.4	0.6	1.5	0.9
0	**0.6**	0.7	1.1	2.1	1.2
-5	**0.9**	1.1	1.8	2.9	1.7
WHITE					
10	**1.7**	3.7	5.6	5.8	5.0
5	**2.0**	4.9	7.0	7.0	6.4
0	**2.3**	6.0	8.3	8.1	7.8
-5	**2.5**	7.0	9.4	8.8	8.8

Robustness of SWLP-GD (contd..)

- Objective measure #2
  - Frequency weighted segmental SNR
  - Gives more weight to spectral peaks as against valleys
  - Correlates well with the industry standard PESQ (a measure of speech quality)
  - SWLP-GD performs better than other representations
  - Most affected: white noise followed by factory noise

Frequency weighted segmental SNR

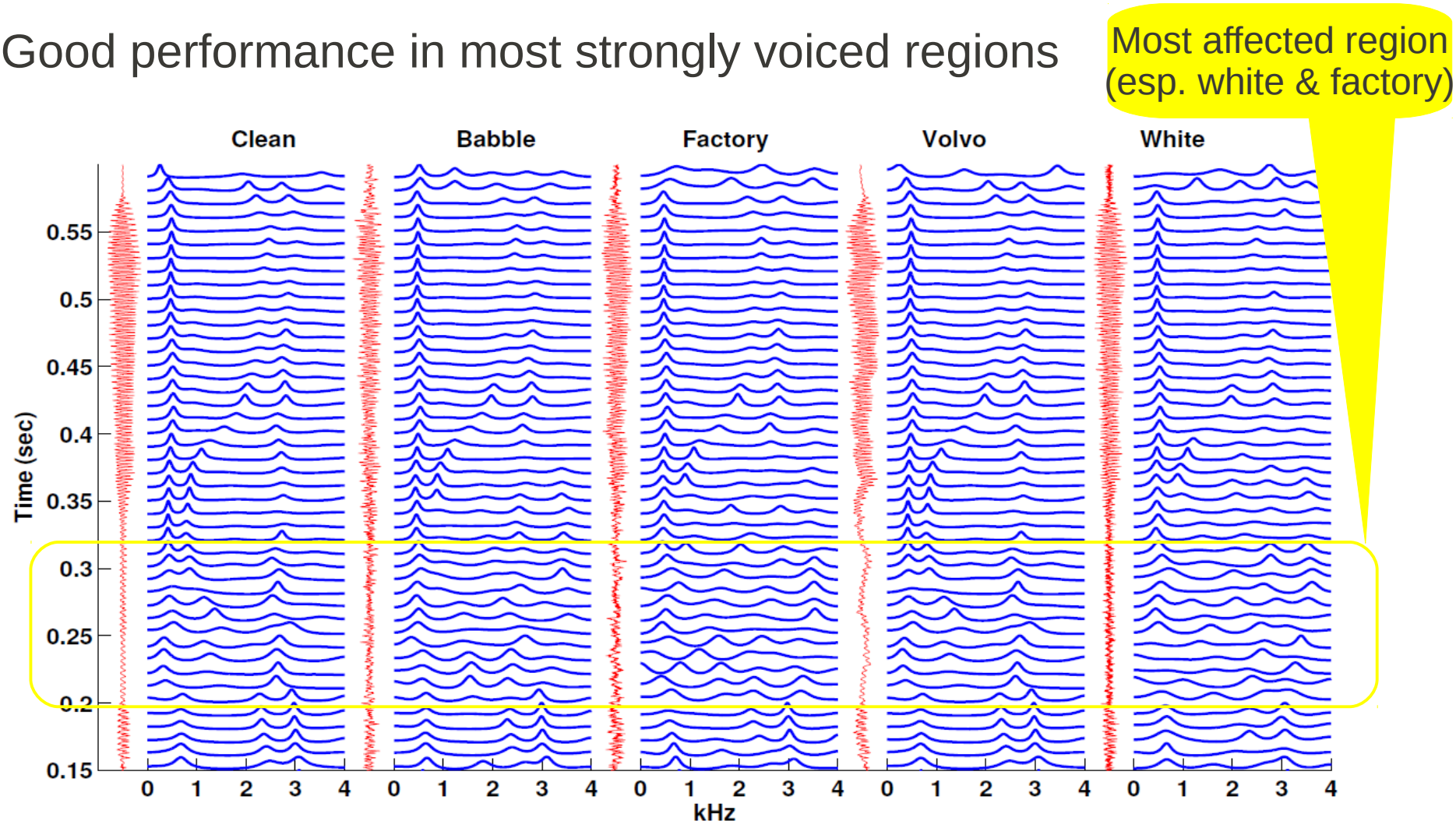
$$S_{fw} = \sum_{k=0}^{K/2} W[k].20\log_{10}\frac{H[k]}{H[k]-\hat{H}[k]}$$

$$W[k] = H^{\gamma}[k] / \sum_{k=0}^{K/2} H^{\gamma}[k]$$

SNR (dB)	SPECTRUM TYPE				
	SWLP-GD	SWLP	LP	DFT	STRT
BABBLE					
10	**24.8**	22.5	18.4	14.8	16.8
5	**21.2**	17.9	13.7	11.2	13.1
0	**18.3**	13.8	9.7	8.3	9.9
-5	**16.1**	10.5	6.6	6.0	7.2
FACTORY					
10	**22.6**	19.6	15.2	12.0	14.5
5	**19.5**	15.0	10.7	8.6	10.7
0	**17.1**	11.3	7.0	6.0	7.5
-5	**15.4**	8.6	4.5	4.2	5.2
VOLVO					
10	**43.2**	42.0	40.6	28.8	34.1
5	**38.0**	37.0	34.4	25.6	29.9
0	**32.5**	31.6	27.8	22.2	25.8
-5	**27.4**	26.4	21.9	18.8	22.0
WHITE					
10	**19.8**	14.4	10.8	9.1	11.3
5	**17.4**	10.2	6.8	6.1	7.4
0	**15.7**	6.9	3.8	3.9	4.5
-5	**14.5**	4.7	1.8	2.5	2.6

Robustness of SWLP-GD (contd..)

- SWLP-GD spectra for different noise degradations at 0 dB SNR
- Good performance in most strongly voiced regions



Speaker recognition experiments

- Small-scale closed-set speaker recognition experiments
  - Matched and mismatched conditions
- Data - VTR database
  - 24 speakers; 8 female, 16 male
  - Train: 6 utts ; Test: 2 utts
  - Degradations: NOISEX database
- Models and features
  - 32 mixture GMMs
  - 12 MFCCs (c1-c12)
- Results:
  - Overall

    48.8% (DFT), **62.7%** (SWLP-GD)
  - Mismatched

    36.5% (DFT), **54.2%** (SWLP-GD)

C – clean case; B10, F10, V10 and W10 – noisy speech at 10 dB SNR (babble, factory, vehicle and white noise respectively)

DFT		Train				
	Degradation	C	B_{10}	F_{10}	V_{10}	W_{10}
Test	C	24	15	6	10	11
	B_{10}	15	24	20	11	10
	F_{10}	9	15	22	4	11
	V_{10}	11	4	10	24	2
	W_{10}	7	2	1	1	24

SWLP-GD		Train				
	Degradation	C	B_{10}	F_{10}	V_{10}	W_{10}
Test	C	24	15	14	19	10
	B_{10}	13	23	18	14	3
	F_{10}	12	23	24	14	14
	V_{10}	22	16	17	24	2
	W_{10}	6	11	14	3	21

Matched conditions

Mismatched conditions with large improvements

Conclusions

- SWLP-GD – key features
  - Provides robust spectral representation for feature extraction
  - Temporal weighting provides robustness in time domain
  - Group delay function provides robustness in frequency domain
- SWLP-GD – *vs* traditional spectral representations
  - lower log-spectral distortion and higher frequency weighted SNR compared to the traditional DFT, LP or STRAIGHT spectra.
  - performs better than the traditional MFCCs in a small-scale closed-set speaker recognition experiments for mismatched conditions of degradation

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Questions?

Thank You!