FUSION OF DIVERSE DENOISING SYSTEMS FOR ROBUST AUTOMATIC SPEECH RECOGNITION SYSTEM

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Motivation

Denoising is essential for robust ASR

- Wiener Filtering (WF)
- Spectral Subtraction (SS)
- Cepstral Mean Normalization (CMN)
- Harmonic Decomposition based noise estimation (HD)

Issues

- Sensitive to parameter settings
- Not robust across multiple noise conditions
- Might require noise specific models

Fusion of diverse denoising front ends

Fusion

- **Inter-system** Denoising algorithms (CMN, WF, SS, HD)
- **Intra-system** Diverse HD parameter settings

Recognizer Output Voting Error Reduction (ROVER)

- Unsupervised fusion of 1-best ASR hypotheses
- Align hypotheses to get sausage network
- Combine by majority voting

Harmonic Decomposition

Algorithm:

- Estimate aperiodic part by least-squares estimation
- Noise estimation from residual using minimum statistics
- Spectral subtraction denoising

Parameter Settings

- Size of running window for NE
- Noise floor level of aperiodic signal
- Noise reduction factor during speech
- Noise factor to compensate for non linear artifact

23 parameter settings $\{p_1, \ldots, p_{23}\}$ chosen.
Objective: Find the 3 subset $\{p_x, p_y, p_z\}$ of parameter settings that is most diverse.

Experimental Setup

Dataset

- Aurora4 dataset
- 6 noise types from 5db to 15db, clean train
- 7138 train, 330 test utterances

ASR

- *KALDI* Speech Recongition toolkit
- Triphone Models
- CMN + LDA + MLLT + SAT

ROVER

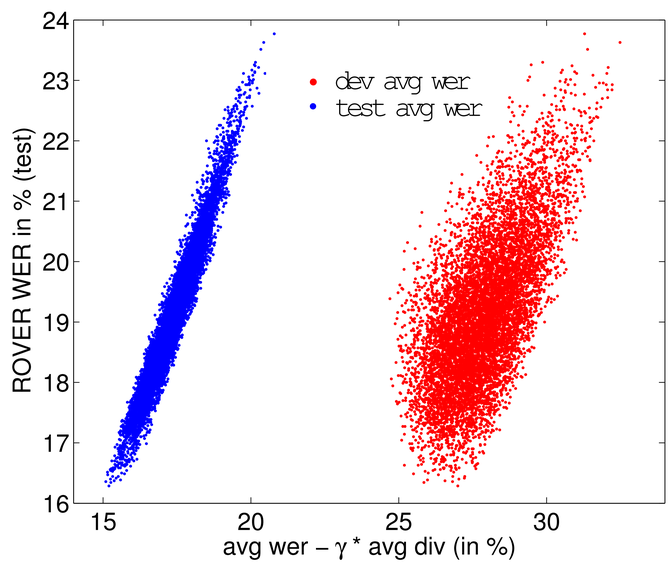
- Word Frequency based (wfR)
- Confidence based (cfR)

Diverse Decomposition Approximation

We use the decomposition proposed in [1]

$$\underbrace{E(r,h^*)}_{\text{ROVER WER}} \approx \underbrace{\frac{1}{K}\sum_{k=1}^{K} E(r,h_k)}_{\text{Average WER}} - \gamma \underbrace{\frac{1}{K}\sum_{k=1}^{K} E(h^*,h_k)}_{\text{Diversity}}$$

h_k Hypothesis by kth system, h^* ROVER system

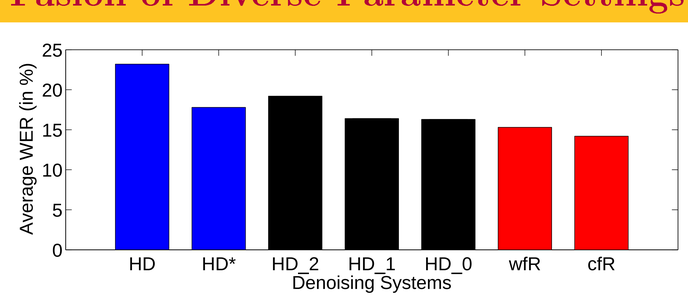


InterSystem Rover

Aurora4, 16kHz, clean condition training.								
	Close Talk							
Test	01	02	03	04	05	06	07	Avg.
CMN	**4.2**	**9.4**	24.1	31.2	25.9	**21.4**	28.1	20.6
WF	4.4	9.7	20.9	26.6	23.0	22.4	23.6	18.7
SS	4.5	10.8	22.9	24.9	22.9	23.0	24.0	19.0
HD*	6.6	12.6	**17.0**	**24.1**	**22.7**	22.7	**19.2**	**17.8**
wfR	4.1	7.9	16.9	22.1	19.0	18.0	18.8	15.3
cfR	3.6	6.9	16.1	21.2	18.2	16.4	18.6	14.2

*n*o noise, car, babble, restaurant, street, airport and train
Parameter setting for HD tuned on a small subset of test

Fusion of Diverse Parameter Settings



- HD_0 best acheivable WER by intra-system fusion
- HD_1 dev average WER
- HD_2 test average WER

Discussion

✓

- Noise type agnostic models
- Tuned on average WER
- Parameters complementary to noise types

?

- Sensitive to γ
- Dev test mismatch
- Search for diverse parameter settings

References

[1] Kartik Audhkhasi, A Zavou, P Georgiou, and S Narayanan, "Theoretical analysis of diversity in an ensemble of automatic speech recognition systems," *IEEE/ACM Transactions on Audio, Speech, and Language Processing*, vol. 22, no. 3, March 2014.