Objective Assessment of Envelope Enhancement Algorithms for Assistive Hearing Devices

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Outline

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Background and Introduction

• Speech understanding in noisy environments with poor signal-to-noise ratio (SNR) is a significant challenge for hearing impaired listeners.

• The poor speech perception for hearing impaired listeners arises from deficits in
  – Spectral processing
  – Temporal processing
  – Binaural processing
  – Cognitive processing
Background and Introduction Cont’d

• This research focuses on enhancing speech for hearing impaired listeners with poor temporal processing

• Recent evidence:
  – Research by Narne et al.[3, 4, 5] showed that a dynamic envelope enhancement (EE) algorithm improves word recognition by listeners with auditory neuropathy spectrum disorder (ANSD)

  – More recently, Shetty & Kooknoor [6] showed that a static envelope enhancement algorithm improved consonant recognition scores by older hearing impaired listeners at different Signal-to-Noise Ratios (SNRs)
Problem Statement

• Previous research considered only subjective evaluation of envelope enhancement algorithms by applying them to short speech segments (consonants, vowels, and words)

• They assumed that there is no background noise at the source location of the speech (e.g. remote microphone)

• Background noise is only added after the speech signal is enhanced and ready to be transferred to a listener
Our Contribution

• Speech perception (at the sentence level) evaluation of the dynamic/static EE algorithms
• Investigation of objective speech intelligibility metrics in predicting the speech intelligibility
• Using the objective intelligibility metric (HASPI) to benchmark the performance of envelope enhancement algorithms in different noisy/processing conditions
Dynamic EE Implementation

- The algorithm first divides the speech signal into a specified number of bands.
- Next, the envelope of the signal is extracted through full-wave rectification followed by low pass filtering.
- Then, the extracted envelope is either left intact or raised to the power $k$ with respect to its instantaneous value.
- A correction factor is obtained by (expanded envelope/original envelope).
- The obtained correction factor is multiplied with the original band pass signal at each band.
- The resulting bands are added to get the enhanced signal.
Enhancing the Envelope by Exponential Law

• $k_{\text{min}} = 0.3$
• $k_{\text{max}} = 4$
• $E_{\text{bmin}} =$ minimum amplitude of the envelope
• $E_{\text{bi}} =$ instantaneous amplitude of the envelope
• $\tau$ (time constant for the exponential) = 0.0001

• Maximum expansion is applied to the lowest envelope amplitude
• Maximum compression is applied to the highest envelope amplitude

$$k_{\text{bi}} = e^{\frac{(E_{\text{bmin}} - E_{\text{bi}})}{\tau}} (k_{\text{max}} - k_{\text{min}}) + k_{\text{min}}$$
Deepen Band Modulation Algorithm (Static EE)

• This technique was recently evaluated by Shetty and Kooknoor [6]
• The algorithm first divides the input speech into 20 bands
• The temporal envelope is extracted
• The envelope in each band is passed through a band pass filter
• Before summing the individuals bands together, a gain of 20 dB was provided to the envelope in channels
Modulation Spectral Energy
Assessment of Envelope Enhancement

• Subjective methods require individuals to judge the quality and intelligibility of the processed speech signal
  – Costly
  – Time consuming

• Computer-based objective measurement have been proposed to estimate speech intelligibility and quality in the presence or absence of background noise

• Objective measurement methods can be divided into two categories
  – Intrusive
  – Non-intrusive
Hearing Aid Speech Perception Index (HASPI)

- Hearing Aid Speech Perception Index (HASPI) [7] is an intrusive measure of speech intelligibility.

- The computed HASPI has value between 0 and 1.
  - Zero means no intelligibility.
  - One means perfect intelligibility.

![Auditory Model Diagram](image_url)
Experimental Methodology

• The dynamic EE algorithm was implemented in MATLAB
• The static EE is available in Praat
• The clean speech sentences used in the present study were taken from the hearing in noise test (HINT) database [2]
  • This test contains 25 lists with each list consisting of 10 sentences
• In the present research study, the Minimum-Mean-Square-Error (MMSE) noise reduction algorithm was investigated as front-end
  • This algorithm was chosen as it generates fewer artifacts (musical noise)

• Objective results are shown as the HASPI scores, averaged over the ten sentences in that randomly selected list
• In conditions involving background noise, the HINT speech-shaped-noise was mixed with the clean speech at different SNRs before applying the noise reduction and/or envelope enhancement algorithms
Experimental Results

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<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
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<td></td>
<td></td>
<td></td>
<td>EE</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
<td>EE</td>
<td>EE</td>
<td></td>
</tr>
<tr>
<td>-3</td>
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<td>EE</td>
<td>EE</td>
<td>EE</td>
<td></td>
</tr>
<tr>
<td>-6</td>
<td>EE</td>
<td>EE</td>
<td>EE</td>
<td>EE</td>
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</tr>
</tbody>
</table>

without noise reduction

<table>
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<tr>
<th>LSNR (dB)</th>
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<th>5</th>
<th>10</th>
<th>15</th>
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</thead>
<tbody>
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<td>3</td>
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</tbody>
</table>

with noise reduction
Experimental Results Cont’d (Modulation Spectrogram for (SSNR=0 and LSNR=3 dB)
Conclusion and Future Work

• Individuals with temporal processing deficits have difficulties in understanding speech in the presence of noise
  • Envelope enhancement algorithms have the potential to improve speech perception for these individuals

• Experiments were conducted to investigate the performance of envelope enhancement algorithms objectively using the HASPI metric

• EE algorithms are effective only in certain combinations of source and listener SNRs

• Performance differences exist among different implementations of EE algorithms
Conclusion and Future Work Cont’d

• The incorporation of a noise reduction algorithm can expand the range of effectiveness of EE algorithms

• Results can potentially guide the choice and activation of EE algorithms in assistive hearing devices

• Benchmarking the performance of EE algorithms with different type of background noise

• Implementing EE algorithms in real time using open source Master Hearing Aid framework
References


References Cont’d


