An Adaptive Directional Microphone System for Quiet and Noisy Conditions

By: *Peter Blamey*
Hayley Fiket
Brenton Steele

Abstract

A new adaptive directional microphone (ADM) has been developed which overcomes problems associated with fixed directional microphones. This new ADM has a flat frequency response from the forward direction, rather than a low frequency roll-off, therefore allowing the same fitting to be used for omni and directional modes. It has the ability to minimize noise from the rear, and to automatically adapt to omni-directional mode in quiet, thus removing the need for manual intervention or multiple programs in the hearing aid. The adaptive microphone has a particularly simple architecture, suitable for implementation in low power applications and in applications where minimal processing cycles are available. The perceptual results show 4 to 7 dB improvements in signal-to-noise ratio compared with an omni-directional configuration, and high user acceptance and preference for the ADM.

Technology

The new adaptive directional microphone (ADM) is particularly efficient to implement on currently available microprocessors, requiring less than 0.5 MIPS for a complete ADM product. This is due to the architecture, which is simple to implement, and inherently supports features that are typically added on to most ADMs.

ADM Polar Response Patterns

The ADM is designed to combine the signals from two omni-directional microphones to enhance sounds arriving from the front of the listener while rejecting signals from other directions. This offers a major advantage over a fixed directional microphone, as noise from any direction can be optimally rejected.

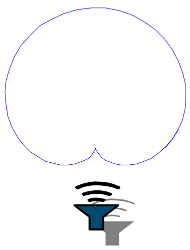

Figure 1.
Noise from the Rear

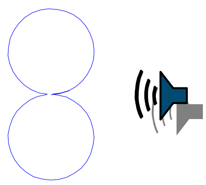

Figure 2.
Noise from the Side

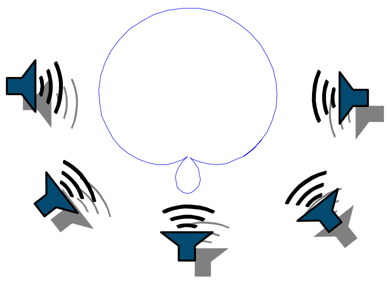

Figure 3.
Diffuse Noise

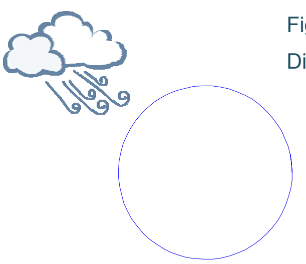

Figure 4.
Wind Noise

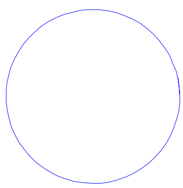

Figure 5.
Quiet environment

Figures 1 to 5 show how the polar response will adjust to reject noise from different directions. In the case of a diffuse sound field, the ADM will adapt to a super-cardioid polar pattern, which is optimal for this situation.

The ADM optimization algorithm also includes an omni-directional response in its range of possible configurations. In situations where a directional response would be particularly noisy (such as when wind causes the two microphone signals to be uncorrelated) the optimization algorithm will automatically adopt an omni-directional response. An adjustable threshold criterion also allows the ADM to adapt to an omni-directional response when the environment is relatively quiet. In this situation the noise rejecting capabilities of a directional microphone are not required and the user usually prefers to be more aware of all of the sounds around them.

Frequency Response

Directional microphones typically introduce a low frequency roll-off that requires compensation. [1] In the case of an ADM this roll-off can also change as the polar pattern adapts. The new ADM presented here has an inherently flat frequency response (as shown in Figure 6) obviating the need for a separate frequency compensation algorithm. The flat response also means that there is no frequency bias in the optimization.

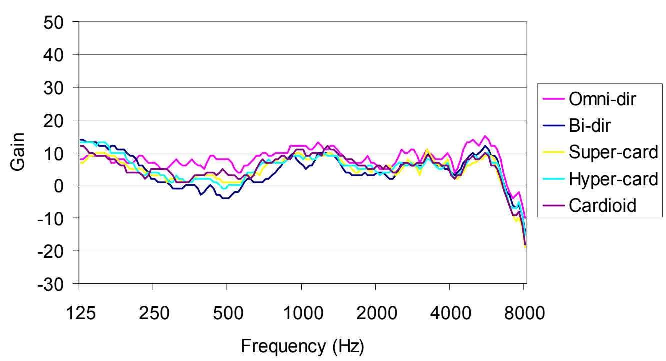

Figure 6. Gain measured in a free-field reverberant environment

Study design

This study compared the performance of a 64 channel ADRO® hearing aid [2, 3] operating in three microphone modes – Omni-Directional, Fixed Directional (super-cardioid) and Adaptive Directional (ADM).

Eight subjects with bilateral sensorineural hearing losses were recruited to evaluate performance when fitted with hearing aids binaurally. The average hearing loss gently sloped from a mild degree in the low frequencies to a severe degree in the high frequencies.

Subjects wore the hearing aids every day for a period of four weeks. An omni-directional microphone was saved in program one and the ADM was saved in program two. The fitting software easily allowed the microphone configuration of program two to be altered between fixed and adaptive directional mode as necessary during the speech perception evaluations described below.

Speech perception evaluations

Two speech tests were utilized to assess performance in a sound booth; the HINT [4] and CUNY [5] sentences. These tests differed procedurally. The HINT is an adaptive test where the speech level increased or decreased depending on the subject's ability to repeat whole sentences. Speech shaped noise was presented at a fixed level of 65 dBA. The CUNY sentences consist of 170 lists with each list containing 12 sentences. Sentences were presented in quiet and in the presence of eight-talker babble.

The speaker arrangements were similar for the two speech perception tests. As shown in figures 7 to 11 all speakers were positioned one meter away from the subject, at ear level. Speech was always presented from an azimuth of 0°. Noise was always presented to the side with the highest pure tone average.

The HINT was performed with noise originating from a speaker located at either 90°, 135° or 180°. The CUNY sentences were performed in quiet, with noise from 90°, noise from 180° and with noise panning between speakers located at 90° and 180°.

Figure 7. Quiet

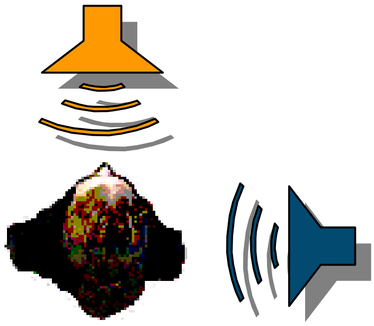

Figure 8. 90 degrees

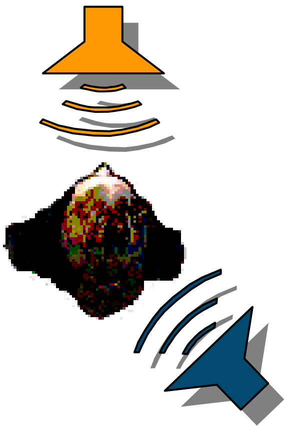

Figure 9. 135 degrees

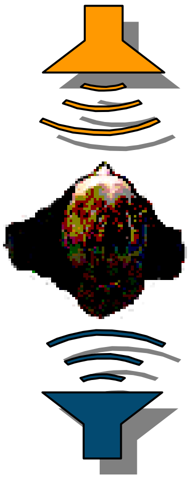

Figure 10. 180 degrees

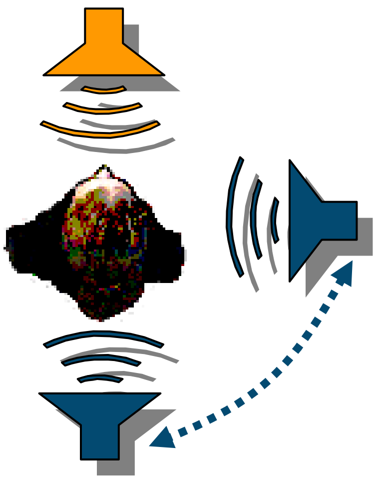

Figure 11. Moving

User Preferences

A Comparative Questionnaire was administered at the last speech evaluation session to assess which program the subject preferred to use in everyday life. The questionnaire asked the subject to nominate the program (omni-directional or ADM) which provided the best listening and understanding for 18 common listening environments. If subjects had not been exposed to a particular situation, they could select a Not Applicable option. If there was no perceptible difference between the two programs, subjects could select a No Difference option.

Results

HINT Speech Perception

The HINT compared speech perception in the presence of noise when aided with an omni-directional microphone, fixed directional microphone, or ADM. The lower the signal-to-noise ratio (SNR) the better the performance of the microphone configuration. As Figure 12 illustrates, the lowest SNRs were achieved when noise was presented from the speaker located at 90° and the highest SNRs resulted when the noise was presented from the speaker located at 180°. The difference between SNR's from the different speaker locations was significant ($F(2, 14) = 17.96$, $p<0.001$). This pattern of results was expected for binaural fittings with a single sound source, largely due to the head shadow effect.

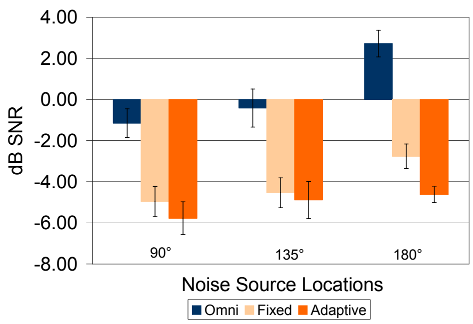

Figure 12. Mean HINT thresholds in noise for 8 subjects

The directional microphones provided improvement in SNR over and above the head shadow effect. For all three speaker locations, there were significant SNR differences between the three microphone configurations ($F(2, 14) = 86.25$, $p<0.001$). The ADM significantly improved the SNR over the omni-directional microphone at all three speaker locations:

- at 90°, ($F(1, 14) = 18.88$, $p<0.001$)
- at 135° ($F(1, 14) = 14.52$, $p<0.05$)
- and at 180° ($F(1, 14) = 95.09$, $p<0.001$).

At 180°, the ADM also significantly improved the SNR over the fixed directional microphone ($F(1, 14) = 38.62$, $p<0.001$).

CUNY Sentence Perception

The CUNY sentences compared the performance of the Fixed Directional Microphone and ADM in four noise conditions. Figure 13 illustrates the percentage of words correct achieved for both microphone conditions in each type of background noise. Combining the four noise conditions (quiet, noise from 90°, noise from 180° and noise panning between 90° and 180°), a one way ANOVA showed that the ADM produced significantly higher scores than the fixed directional microphone, ($F(1, 126) = 9.97$, $p<0.05$).

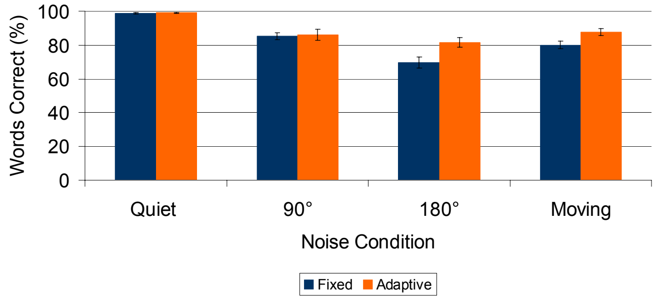

Figure 13. Mean CUNY sentences scores for 8 subjects in 4 noise conditions

Comparative Questionnaire

A total of 144 responses were received for the Comparative Questionnaire. Twelve responses were judged as not applicable for the subjects and were not included in further analysis. Of the remaining 132 responses, subjects judged that there was no difference between the omni-directional program and the adaptive program 29% of the time (38 responses). They also judged that the omni-directional program was preferred 17% of the time (22 responses) and that the adaptive program was preferred 54% of the time (72 responses). This difference was highly significant ($\chi 2=26.6$, $p<0.0001$).

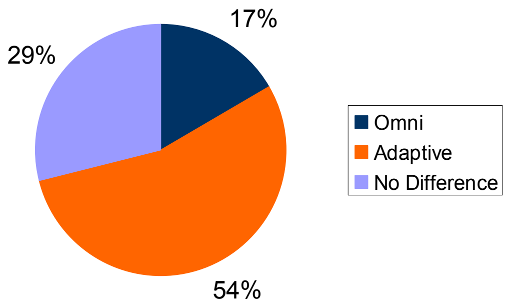

Figure 14. User preferences with Comparative Questionnaire

Conclusion

The ADM tested in this study provides more benefit than both an omni-directional and a fixed directional microphone. Listeners gain benefits in a variety of environments without having to switch modes manually.

Acknowledgements

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