An Investigational Study into the Design of a Low Cost, Adaptive Hearing Aid

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Objectives

To develop an inexpensive hearing aid that has all of the functionality of a high-end hearing aid, including:

- Amplifying specific frequency bands according to a person's audiogram
- The ability of the user to select the direction in which they wish to listen and to hear sounds in that direction louder than those from other directions [1]

This is achieved by creating:

- A full software hearing aid simulation
- A hardware proof of concept of a hearing aid which demonstrates limited functionality

System Design

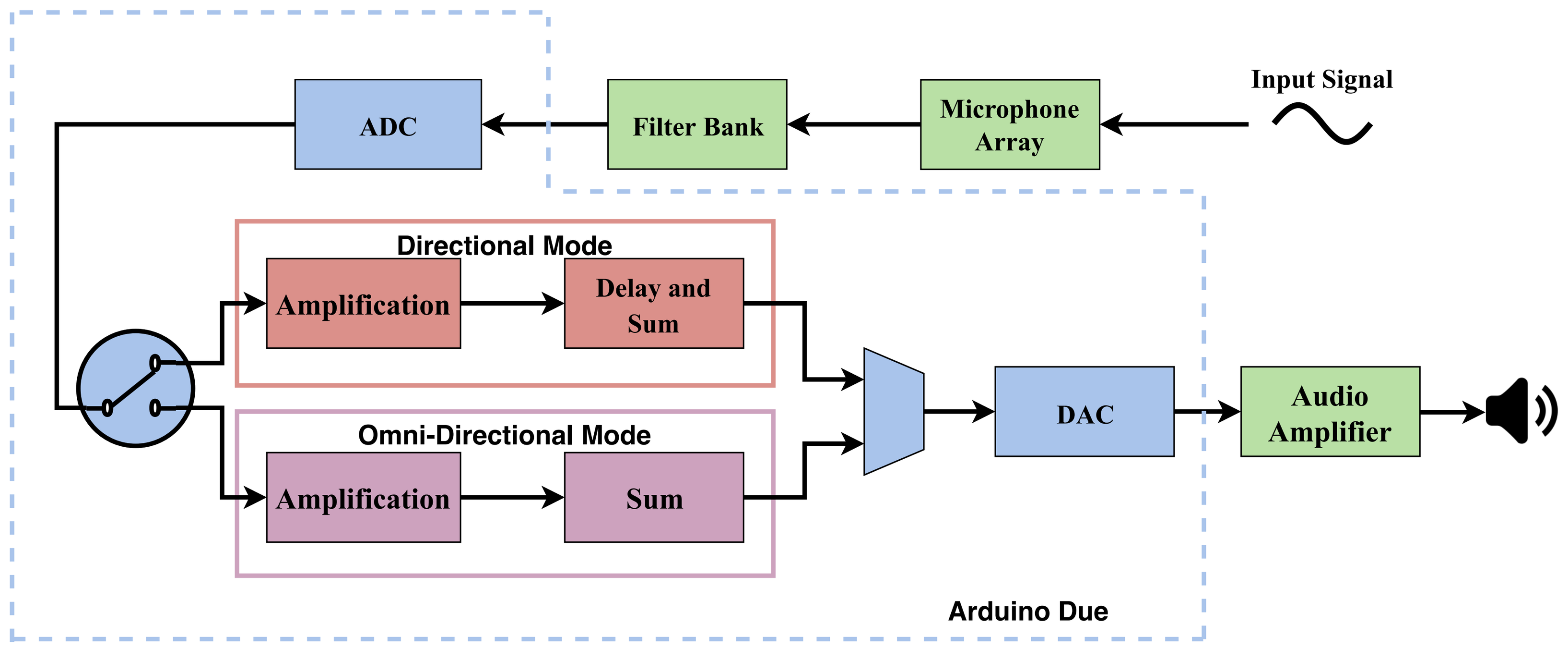

Figure 1: Hearing aid system overview [2]

Simulated vs Hardware Hearing Aid

Table 1: Comparison of simulated and hardware hearing aids

Property	Simulation	Hardware
Number of Microphones	10	4
Bandwidth	0.25-8 kHz	2.8-3.5kHz and 5.6-7 kHz
Filter order	14	2
Type of filters	$\frac{1}{3}$ Octave bandpass	$\frac{1}{3}$ Octave bandpass
Number of filters	16 per microphone	2 per microphone
Number of steerable angles	19 (10^o increments)	5 (0^o, 60^o, 90^o, 120^o, 180^o)

Device Testing

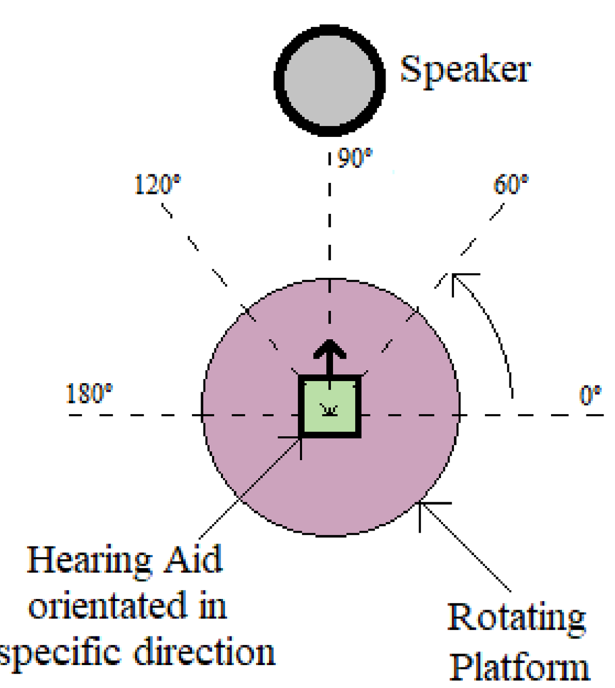

Figure 2: Procedure for testing the hearing aid

Results: Simulation

In the figure below, the frequency spectrum of the output from the hearing aid is compared to that of the original signal so that the effects of compensatory amplification can be seen

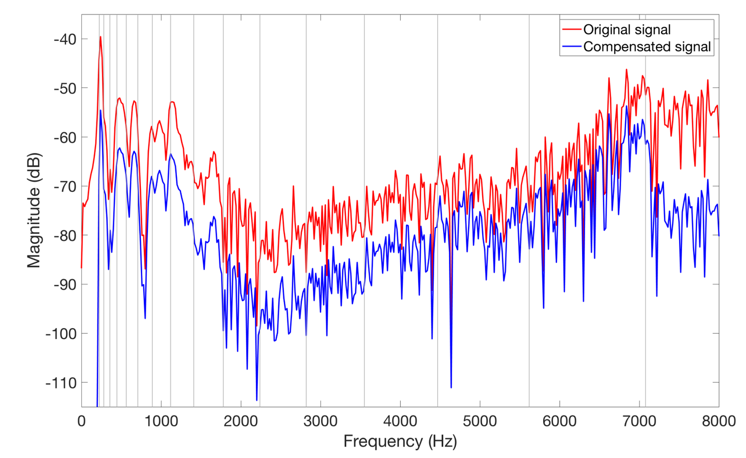

Figure 3: FFT of the input signal and the output signal from the hearing aid

The polar plot shows the normalised magnitudes of the signal at various angles, with respect to the user, when the dial is facing 90^o

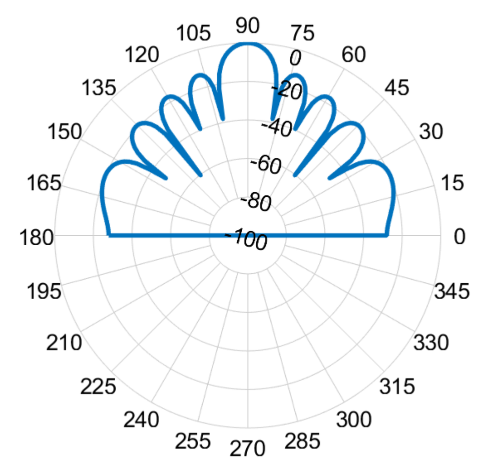

Figure 4: Gain applied to the output signal when the beam is steered to 90^o

Results: Hardware

The effects of compensatory gain are illustrated below through the application of different amplifications to the two frequency bands

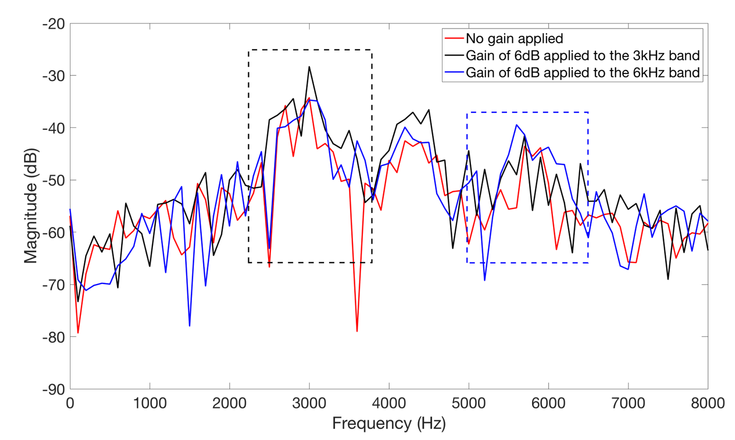

Figure 5: FFT of the output signal from the hearing aid with various amplifications

A simulated response was created using 4 microphones. This response was compared to the measured response acquired during device testing

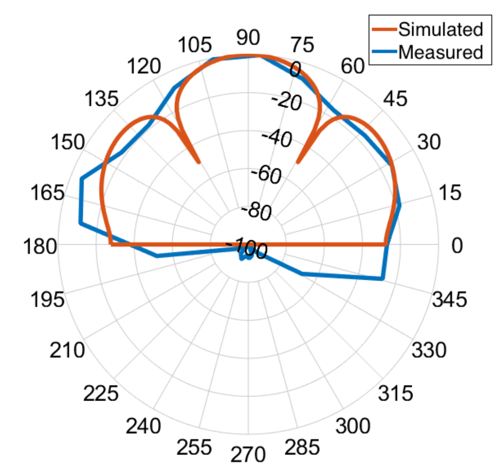

Figure 6: Gain applied to the output signal when the beam is steered to 90^o

Results: Hardware

Compensatory gain error was calculated using the difference between the desired and measured gain at the centre of each frequency band

Table 2: Error in compensatory gain

Frequency band (kHz)	Error (%)
2.8 - 3.5	0.81
5.6 - 7	19.56

The error in the beam steering ability of the directionality feature was calculated by comparing the measured and the simulated polar plots for each steerable angle

Table 3: Average error in directionality

Angle (^{o})	Average Error (%)
0	46.6
60	30.7
90	12.7
120	22.7
180	51.7

Future Work

For future development of the hearing aid, a number of improvements could be made including:

- Making use of higher quality omni-directional microphones
- Creating an integrated circuit chip to handle the preprocessing of the audio signals
- Making use of more microphones to improve the precision of the beam steering in the directionality feature
- Emdedding the microphones and circuitry into headphones to reduce the size of the device

Conclusion

This project is a proof of concept that an inexpensive, fully functional, adaptive hearing aid can be produced. This was proven by:

- Amplifying specific frequency bands in accordance with individual audiograms
- Steering the acoustic beam to attenuate signals in directions other than the selected one
- Creating a hearing aid that costs R1500

Overall device accuracy:

- Average error in the measured gain when compared to the desired gain is 10.2%
- Average error between simulated and measured steered beam is 32.9%

References

[1] D. V. Anderson, R. W. Harris, and D. M. Chabries. Evaluation of a hearing compensation algorithm. *1995 International Conference on Acoustics, Speech, and Signal Processing*, 5:3531–3533, 1995.

[2] Uwe Rass and Gerhard H. Steeger. Evaluation of digital hearing aid algorithms on wearable signal processor systems. *1996 8th European Signal Processing Conference*, pages 1–4, 1996.