CYBERNETIC HEARING ENHANCEMENT

EASY TO USE, OPEN SOURCE HEARING TECHNOLOGY

My 101 year old grandfather is experiencing severe hearing loss. The hearing aids he was prescribed cost €1500, and he can't operate them himself, the feedback screeched unbearable noise into his ears, and the only way to turn them off and on is to take out the batteries... And the batteries don't last long.

So one day we gave him an old field recorder mic with earbuds, a piece of professional audio equipment which costs under €100. We turned on dynamic range compression and volume limiting. His hearing improved immediately, and the setup can be turned on and off with a flick of a switch, so it's easier for him to use. Even these basic DSP effects improved upon the medical state of the art.

We realised how badly the hearing technology space needs reform, and that modern audio knowledge could improve it. With Brett's cutting-edge audio expertise, and our shared programming knowledge and a commitment to accessibility and open-source values, we are in a position to do this. That was the origin of this project.

- Eva

We propose to begin by creating easy to use, free and open source software for people with hearing loss, to use with affordable off-the-shelf hardware with a simple upload of software with or without a custom hearing profile. We would like to then continue by creating custom hardware to further outperform hearing aids.

The goal is to use cutting-edge digital signal processing to provide noise reduction, dynamic range compression, limiters for loudness control, and frequency adjustment for everyday use. There is no good reason why most hearing technology today doesn't do a good job of this.

We would like to create something that can be used by anyone, regardless of technological affinity, with any microphone and earbuds, with an optional setup that can be customized to a person's auditory profile.

The landscape

The hearing aid industry is worth an estimated $9.8 billion, and shows signs of cartel pricing. It is slow to adopt progress in audio technology. The sound quality, feedback, and ease of use of hearing aids can be awful, especially considering that they are often meant for seniors. We do not hope to enter the industry of medically-accredited devices, due to gatekeeping, and do not call our project a “hearing aid” – but we hope to outperform it still. We will call it hearing enhancement.

There are commercial efforts to enter this space, including by the leading technology corporations. These are sometimes more accessible, but proprietary, and raise privacy concerns. They include many smartphone apps that are predatory, operating on a subscription model that puts them out of range for many people, especially in the poorer areas of the world.

There have been some open source efforts to solve these problems. We analyzed their progress with interest. Their main shortcoming appears to be lack of ease of use, however, building upon their work should be part of the strategy.

5 hearing aid manufacturers hold 99% of the global market share.[1] This results in little innovation and cartel pricing. Sale prices are often on the order of thousands of Euros[2] and rental prices in hundreds per month.[3]

Hearing enhancement smartphone apps tend to charge on the order of 15-20 euros per month. The market leader, Hearing Clear, includes loud ads played directly into your ear. Apple includes hearing aid tech with its Air Pods Pro 2 which eclipses the industry standard,[4] and should be viewed as the current benchmark.

[1] https://mysecondear.com/blogs/wissen/hoergeraete-hersteller-marken
[2] https://www.hearingtracker.com/hearing-aids/compare
[3] https://www.hearinglife.ca/hearing-aids/prices
[4] https://www.apple.com/airpods-pro/hearing-health/

We present a comparison of these technologies, and some open source efforts, on the next slide.

A COMPARISON OF SELECTED HEARING AID/ENHANCEMENT TECHNOLOGY

	Type	Price	Ease of use	Open source	Audiogram interface	Volume limiter	Noise reduction	Feedback cancellation
JLab HEAR OTC	Budget off-market hearing aid	Under €100, doctors don't prescribe it	Seniors may need assistance	No	No	No	No	No
Sony CRE-C20[1]	"Budget" medical hearing aid	€900	Seniors may need assistance	No	Yes (reviews are critical)	Some	Some	Some/bad
Horizon Go IX[1]	High-end medical hearing aid	€3000-€5000	Seniors may need assistance	No	Doctor's appointment	Yes	Yes	Yes
Hearing Clear[2]	Commercial app, #1 in Play Store	$14,99/month +ads	Seniors need assistance	No	No	No	Not very good	No
Apple AirPods Pro 2 Hearing Aid	Corporate feature	Included with Airpods Pro 2 (€279)	Pretty good	No	Yes	Yes	Yes	Some
Hearing Aid App for Android[2]	Commercial app	$22/week	Seniors need assistance	No	No	No	No	No
Augmented Hearing	Danish startup	Unreleased yet	Unreleased	No	No	Yes	Yes (neural network)	Yes
Tympan	Open hardware	€700 hardware	Requires coding	Yes	No (requies an upload)	Programmable	Programmable	Programmable (very good)
OpenMHA	Academic project	Off-the-shelf hardware	Requires coding and hardware expertise	Yes	No	Yes	Yes	Yes

[1] https://www.hearingtracker.com/hearing-aids/compare

[2] Android Apps seem to all have high latency, and all they seem to do reliably is a volume boost.

OPEN SOURCE EFFORTS

Tympan [1] is the best developed Open Source hearing project. It has impressive features. However, it highlights some ways in which we should do better. The customised Tympan Teensy processing unit is priced at a disappointing €300.00, with earpieces for €400.00. The set up requires programming knowledge.[2] One needs to upload one's hearing profile, obtained in some other way. We aim to create a solution that works with an easily available off-the-shelf processing unit, earbuds and mic for under €150.00 total.

OpenMHA [3] is an impressive academic project which has many DSP effects implemented and a lot of useful code, that can be used with off-the-shelf hardware. There is much room for improvement in accessibility, as it is also aimed at highly technical audience, researchers, and industry professionals.

Crescendo [4] is focused on musical frequency correction, spectral gain compression and psychoacoustics. Its functionality can be performed by any music production spectral compressor software.

[1] https://tympan.org https://forum.tympan.org/
[2] https://github.com/Tympan/Docs/wiki/Getting-Started-with-Tympan-Rev-E
[3] https://www.openmha.org/
[4] https://github.com/dbmcclain/Crescendo-Hearing-Correction

THE INITIAL VISION: USING AFFORDABLE, OFF-THE-SHELF HARDWARE

A plug-and-play open hardware device, that is small, cheap, operated with a single switch and can be made with readily accessible parts. We will create the software, that will work with people's favorite earbuds and any standard mic. This looks more casual than a hearing aid.

Software should be easily uploadable and work immediately, with a UI for optional customisation.

Most promising off-the-shelf devices:

- Raspberry Pi / Raspberry Pi Zero + audio input
- Teensy / Arduino + audio input
- Daisy Pod (includes audio)
- ESP32

Earbuds or headphones

Microphone: Lapel mic, stereo input

3D Printed case

Battery pack

The vision – software

The stand-alone device solution has two software components:

1. DSP software to upload or flash onto the hardware. The easier to use the better, a simple upload to an off-the-shelf device would be best.
2. Software to customize a device to a person's auditory profile. This should mimic a medical audiogram process.

The smartphone app route: Apple's *AirPods Pro 2* include a solution called *Hearing Health*, and it is functionally good. While it raises concerns about corporate control and privacy, it has a good effects chain and an audiogram interface.

There are hearing technology apps available for Android, but they have disappointing sound, latency, predatory pricing models, and can damage a user's hearing due to a lack of volume limiters. The latency seems to be a common issue with Android audio and we are exploring ways to overcome it.

Faced with the Apple ecosystem having a decent solution, we propose to focus on creating a solution using a standalone device, as wells as to further explore the Android app route.

Example DSP effect chain

1. High pass filter at 50Hz - 100Hz - to remove unnecessary bass and rumble that takes up headroom in the audio signal
2. Low-pass filter - smooth rolloff of high frequencies
3. Noise reduction - remove hiss, hum, wind, and other not useful sounds
4. Multi-band upwards and downwards dynamic range compression - to make quiet sounds loud and reduce loud sounds to a reasonable level
5. 8 band equalizer – for tuning to each user's hearing profile
6. Limiter – Safety from sudden spikes in loudness
7. Feedback cancellation – in case the mic picks up audio from the headphones. Many projects, even the ones that are not a complete in-ear device, place the mic near the ear. We believe this is unnecessary unless for phase cancelation purposes.

Demo:

Before	After
	
	

AI NOISE CANCELLATION

There have been promising neural network tools in development for noise cancellation, such as RNNoise or WaveNet. They are compact and not resource intensive, and RNNoise can already run locally on a Raspberry Pi, or in a phone app. We hope to refine our own model for the purpose, and in the long run create tools that will help refine the model for an individual user's needs.

Target budget for the initial phase:

The hearing aid industry is valued at $9.8 billion, and projected to grow. We can outperform it, and create a free and open source alternative for €40,000. The work should include:

- Documented device evaluation
- Making the real-time, specialized DSP software
- Making the software easily run on a target device without complicated setup
- Making the audiogram GUI for optional configuration and customizing the DSP to each person's hearing profile
- Website: documentation, instruction and outreach videos, links to ways of buying the hardware, mic and earbuds recommendations
- 3D print files for a case, instructions on how to order one online and a recommendation for an off-the-shelf solution

Who are we?

We have both collaborated with the NLnet foundation before, on the Katzenpost Metadata-Minimizing Messenger project. Importantly, in that collaboration Brett delivered the Rustic Audio DSP, software which can prove partially relevant for this project.

Brett Preston is a cutting-edge audio software engineer, and his knowledge of the latest audio techniques is the foundation of this project. He made Rustic Audio, a Rust-based DSP developed with NLnet support, meant to improve the sound quality in highly compressed voice audio, to fit the setting of private messengers with limited bandwidth. The tool is versatile and appropriate for cleaning audio.

He is also a music producer, sound designer, composer, has been an audio director in VR gaming, and a generative 3D artist, who creates 3D visuals and experiences.

https://github.com/brettpreston/Rustic_Audio
https://zaga.music
https://brettpreston.github.io

Dr Eva Infeld is a mathematician with publication combinatorics, probability theory, and computer science, a coder, a grassroots organiser, and brainstormer. She is a researcher on the Katzenpost Project, an NGI grantee. She went from working in academia to working on privacy software, and has been a part of the FOSS community for over a decade.

https://evainfeld.github.io/

We have also sought the advice of doctors from the Warsaw-based **World Hearing Centre** , as well as multiple people experiencing hearing loss. There are diverse causes of hearing loss and not all of them can be addressed with a tool of this type, or any hearing aid. But for those that do use hearing aids, trials with a PoC setup with the DSP have so far outperformed industry-standard devices.

https://whc.ifps.org.pl/

Thank you for your consideration!