Fakultät I
Institut für Sprache und Kommunikation
Fachgebiet Audiokommunikation

Master Thesis Exposé

# Ultrasonic Cyborg Hearing

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# Abstract

This thesis will explore the extension of the senses through technology. Past and present efforts to augment the human perception technologically will be examined. The focus will be placed on the efforts undertaken by the do-it-yourself cyborg and biohacker scene. In order to gather practical experience in the field through a creative critical approach a prototype will be developed to transpose sound from the ultrasonic range into the human audible range. The device will be cybernetically tied directly into the auditory nervous system using a cochlear implant.

# Introduction & Motivation

Perception shapes our reality. Ancient Greek philosophers had already established this connection between the human perception and the gain of knowledge or truth. One famous example would be Plato's "Allegory of the cave", where the perception of shadows reveals truth about the objects casting the shadows to the observer. Although the human sensory input systems are quite sophisticated, they have evolutionarily specialized and adapted to our environment in order to help us survive. Nevertheless they only offer us a small window into a slice of the electromagnetic or acoustic spectrum, leaving many natural and technical processes imperceivable and hidden from us. Through technological advances humans have continuously developed and improved tools to help them overcome those natural limitations and improve their senses. These extensions of the senses through technology have helped humankind to achieve feats previously impossible and gain insights into domains thought to be inaccessible, for example viewing far away objects or perceiving infrared or ultra violet light. This notion still holds true today, as every new evolution in observation technology offers new methods for discovery and gaining knowledge.

In recent years observation technology and electronics in general has become much more accessible. As a result of the mass production and miniaturization of silicon semiconductor chips and sensors it has be come feasible for interested makers and hackers to build their own electronic devices affordable at home. This has enabled a growing community of biohackers and do-it-yourself cyborgs, interested in manipulating or extending their own senses through technological means, to experiment. Cyborg is the term for an organism composed of both organic and electrical or mechanical body parts. This form of merging humans and machines has been a topic in fiction since the 1960s. Through the continuous advances in technological development it has recently become an on-going topic of growing importance with real world future implications for humankind. As a cochlear implant wearer, my sensory nervous system is already connected and stimulated by electronics, which makes me a cyborg according to the traditional definition. Cochlear implants offer people with profound hearing loss a new auditory impression, enabling them to hear again. In this thesis I would like to develop and test a device to extend the capabilities of my cochlear implant into the ultrasonic range, making it possible for me to gather some practical experience in cybernetic augmentation of the senses. It also allows a redefinition of the cochlear implant from a way to mitigate a "disability" to a practical way to extend the human perception beyond its natural form.

# State of the Art

Tool usage by humans in order to understand and manipulate their surrounding environment dates back to prehistoric times and is even regarded as one of the facets of intelligence that sets humans apart from many other animals. One of the historically most significant advances in the domain was the extension of the human optical sense through the development of the lens. This lead to a variety of different sensory extensions among others the telescope, the microscope and later the glasses. The invention of the telescope had huge implications for understanding the universe and the relationship between the earth and other objects in the night sky. The resulting discoveries permanently shaped our understanding and view on the world. It was also essential for navigation and observations. Similar to the telescope the microscope opened up new worlds for science and technology to explore. It allowed studying objects far to small for human vision to resolve, like red blood cells, bacteria, insects or mineral deposits in rocks. Those observations in turn gave rise to entire new fields and subcategories of science and medicine, which lead to the development of pharmaceuticals, germ theory or precision manufacturing techniques just to name a few. On a more individual level the lens was the key component in developing glasses which enabled people to see better and counter loss in vision. The gain of knowledge and improvements in life conditions with each evolution of perception extending technology still continues today. One modern example would be the availability of handheld infrared cameras. They not only allow researchers to see at night to study nocturnal animals, but also help firefighters to inspect extinguished fires for pockets of embers or hotspots to make sure they are permanently extinguished.

The recognition of the connection between perception and reality has also been incorporated by the do-it-yourself cyborg and biohacker scene. They have conducted a variety of different practical experiments and trials on augmenting and extending the human senses. Many smaller cybernetic body modifications are popular with interested individuals. Among the most popular implantations are NFC or RFID chips for storing and reading out small amounts of data. As the most common extension of a sense a number of people have implanted small magnets under their skin. This implant enables sensing of magnetic fields through a tingling sensation as well as picking up small ferromagnetic objects. A few people have delved deeper into the subject and have undertaken more pervasive modifications. Most well known is the cyborg activist and artist Neil Harbisson, who was born color blind and has developed an antenna which translates color information into sound. The antenna is implanted into his skull where the sound is transmitted through bone conduction to his brain, giving him a new sense for color. While the cyborg scene has steadily grown and continuously caught media attention, it has become a bit more quiet in the past 5 years.

In the domain of making ultrasound audible for human ears there is a range of devices available for sale. Almost all of them are geared towards bat observation and come with a hefty price tag starting at around 100-200 € and going well into the thousands. Despite the high price their construction and performance is quite basic. Most of the devices use the rather simple heterodyne algorithm for shifting the pitch of the ultrasound signal into the audible range. While it does make the sounds audible, it simply shifts all frequencies by a constant amount thus destroying all harmonic relationships between them, distorting the sound. This might be sufficient for perceiving bat sounds, but for an ultrasonic hearing sense it would be desirable to scale the frequencies correctly in order to preserve their harmonic relationships. New developments in the field have recently been conducted by Finish researchers. They have experimented with spacial hearing for sound localisation in the ultrasonic range using multiple microphones.

The state of the art in pitch shifting using digital signal processing (DSP) is rooted in research from the 1990s and early 2000s. Basic principles have not changed much since then, but many different specialized implementations have since been developed. Especially the music industry has employed algorithms that produce little harmonic distortion, but are sometimes too computationally intensive to work in real time. They usually also produce audible artefacts when transposing tones over many octaves. Both realtime execution and large scaling factors are properties that will very much be needed for an ultrasonic hearing sense.

# Methods

As part of this thesis I would like to build a working prototype. The prototype acts as a proof of concept and is supposed to be able to capture ultrasound and transpose it into the audible range. It will then be connected to the cochlear implant and stream the transposed sound directly to it. Currently the device is planned to be composed of a microphone sensitive in the ultrasonic range, a chip with an analog to digital converter for capturing the audio data and a microcontroller for processing. In contrast to the other available ultrasound listening devices the parts should be cheap and readily available. The design goal would be for the total hardware cost to stay below 50 € to encourage others interested to replicate the device.

On the software side a digital signal processing algorithm will be implemented to transpose the sound into the audible range. This will happen in real time. Instead of a simple shift the algorithm will scale the frequency spectrum with respect to the harmonic relationships between notes so that they are preserved. The code will be well documented and released under an open source license to enable others to use it for their purposes.

The impressions and results of using the prototype and integrating it into the normal hearing experience will be highly subjective in nature. In order to put them on record I will write a personal field report and document the impressions and experiences I observed using it.

# Structure & Timeline

The structure of the thesis is roughly split into four parts. It will start with a short introduction and a chapter containing a few sections that will provide background information and context on some topics touched by the thesis. These include for example ultrasound, cochlear implants or pitch shifting. Then a detailed look on past cybernetic body modifications and extensions of the senses will follow in the next chapter. The practical part will include a description of the working prototype, its parts and the inner workings as well as the software and algorithms used. Finally a personal experience report will document how the prototype feels and works under real world conditions.

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| August 2021 | Literature research |
| September 2021 | Sourcing of hardware parts |
| October 2021 | Programming, optimizing & testing software |
| November 2021 | Prototype field tests |
| December 2021 | Thesis writing |
| January 2021 | Thesis writing |

Thesis timeline