Development of an Intra-Aural Protective Device for Hearing-Impaired Individuals Working in Noisy Environments

Solenn Ollivier *[1], Hugues Nélisse †[2], Fabien Bonnet[2], Rachel E. Bouserhal[1], Christian Giguère[3], and Jérémie Voix ‡[1]
[1]Université du Québec, École de technologie supérieure, Montréal, Québec, Canada
[2]Institut de recherche Robert-Sauvé en santé et en sécurité du travail, Montréal, Québec, Canada
[3]Université d'Ottawa, Ottawa, Ontario, Canada

1 Introduction

Occupational hearing loss (OHL) is one of the most common occupational diseases, affecting 16 to 24% of the population worldwide [1, 2]. For this sensorineural type of hearing loss, permanent damage is caused to the inner-ear organs after repeated hazardous noise exposure. OHL not only has an impact on hearing and communication capabilities, but also contributes to unemployment, social isolation and psychological disorders. In Canada, approximately 40% of workers have reported being exposed to hazardous noise exposure [3]. Hearing impairment, whether it is noise-induced or age-related, causes difficulties in communication as well as in the perception and localization of sound. Due to the slow and stealthy onset of hearing loss coupled with an aging working population, more and more workers in the industry suffer from hearing impairment. In a work environment, the consequences of impaired hearing include difficulties to perform tasks and communicate efficiently, as well as safety issues. To mitigate these consequences and to keep doing their job in a safe, efficient and autonomous way, most hearing impaired workers wear hearing aids while at work. However, while these devices appear as a preferred solution, their use in a noisy environment raises important challenges. Even though remarkable progress has been made to improve fitting algorithms in the last decade, they are not specifically designed for use in a noisy workplace. In fact, audiologists usually recommend not to wear hearing aids when being exposed to loud sounds. Current products are not yet able to recognize sounds of interest, thus amplifying already high level ambient sounds, and increasing the risk of further hearing loss. Moreover, no reliable existing solution can assess the noise exposure of workers wearing hearing aids [4].

A recent study on workers needing to wear hearing aids, and their work conditions, highlighted four main guidelines : 1) the establishment of recommendations to support hearing-impaired (HI) workers, 2) research on a reliable noise exposure measurement method for HI individuals in professional settings, 3) the development of an intra-aural device with features of both a protector and a hearing aid which could directly measure the noise dose, 4) study of the benefits of active sound restoration devices through electroacoustic and psychoacoustic measurements [4]. This paper focuses on the methods and preliminary works around the implementation of hearing aid algorithms on an intra-aural device intended to be used as both a hearing protector and a hearing aid.

*. sollivier@critias.ca
†. hugues.nelisse@irsst.qc.ca
‡. jeremie.voix@etsmtl.ca

2 Creating a protective hearing aid

Following the third recommendation of Leroux *et al.* [4], a solution to support HI workers is to develop a unique protective hearing aid device that can allow for both sound attenuation and amplification to communicate properly in noisy environments. In this project, hearing aid algorithms will be implemented within a device that features two earpieces, each instrumented with a loudspeaker and two microphones, such that the final prototype offers benefits from both hearing aid and hearing protection devices. Not only will this device amplify and protect, it will also monitor the individual's noise exposure and provide research evidence on the needs of hearing-impaired workers in loud workplaces. To this aim, in-ear dosimetry will be included for real-time monitoring of the wearer's noise exposure. Combining these three features into one single intra-aural device to create the final prototype could reduce the risk of further hearing loss among HI workers and enhance the development of a unique platform for research.

The development will follow two main phases. The first phase consists of the platform and prototype development. Laboratory tests and electroacoustic measurements will provide guidance in choosing key features for hearing aid algorithms, including wide dynamic range compression (WDRC), hearing aid fitting algorithms and filters. These algorithms, alongside those for in-ear dosimetry, will be implemented in MATLAB (MathWorks, Natick, MA, USA) and tested on an acoustic test fixture. After being implemented on the hardware, further described in section 3, the algorithms will be tested to evaluate the benefits of continuous monitoring and fitting algorithms while simulating low to severe hearing loss.

The second phase will consist of subjective measurements on human subjects such as psycho-acoustic tests. A wide range of conditions typical of industrial noise environments will be tested, with speech and non-speech signals. This validation step will enable a better understanding of how to practically adapt hearing aid algorithms and parameters in various noise environments.

3 Developing hearing aid compression algorithms

The final prototype will use the TYMPAN.org open platform (under MIT license, Massachusetts, USA), an open source hearing aid development platform that includes a hardware audio board featuring a Teensy 3.6 programmed with an 8 band WDRC. It can be used with Arduino and Teensyduino add-on, and transmit information to the two aforementioned earpieces. Aside from the WDRC algorithm used, one of its benefits is the possibility for it to provide binaural sound transmission. Before the final algorithms are implemented in TYMPAN, simulations aiming to select the right programming features and parameters will be performed on MATLAB. The architecture of the hearing aid algorithm will be inspired from the hearing aid simulator coded in the MATLAB Speech Testing Environment (MSTE), initially designed to allow measurement of speech reception thresholds (SRT) under various listening and processing conditions [5]. This hearing aid algorithm includes a signal-enhancement module with noise reduction algorithms, the NAL-RP linear hearing-loss prescription [6], an amplitude compression algorithm implementing an input-controlled automatic gain control (AGCi) system, a volume control block, an amplitude compression algorithm implementing an output-controlled (AGCo) system, and symmetric peak or center clipping.

WDRC demonstrates better opportunities when it comes to speech recognition in noise for individuals with moderate to severe hearing loss [7]. Splitting the signal into bands allows to independently adapt compression features depending on the frequency range. The number of bands should be chosen by finding a compromise between vowel recognition (wider range compression needed) and consonant recognition (smaller dynamic range needed) [8]. The 8-band WDRC algorithm from TYMPAN seems to be a good fit for the hearing aid device wanted and will be tested.

4 Preliminary Results

To later run the simulations through MATLAB, the WDRC code was transferred from TYMPAN to MATLAB. Filter and compression functions were compared at the outputs of TYMPAN and MATLAB. The filterbank implemented in TYMPAN is made up of third order successive Butterworth filters. Their linearity and flat response in the pass band make them ideal for hearing aid algorithms. The consistency between the MATLAB coded filter and the TYMPAN original filter is verified by comparing the filter spectrum from TYMPAN to the one of a white noise signal passed through the MATLAB filter. As shown in figure 1, the MATLAB coded filter response, illustrated by the solid line, is the one expected with cutoff frequencies being consistent.

The compressor response was also studied and compared. While speech treatment seemed to be consistent between TYMPAN and MATLAB, noise was clearly compressed with the TYMPAN version and not with the MATLAB coded compressor. This can be due to the adaptive feedback cancellation part of the TYMPAN algorithm that was not implemented in MATLAB.

5 Conclusions

The need for a device able to combine sound amplification, sound attenuation and dosimetry has been established. To achieve this, algorithms must be developed, implemented and tested using, at each step, the most advantageous platform.

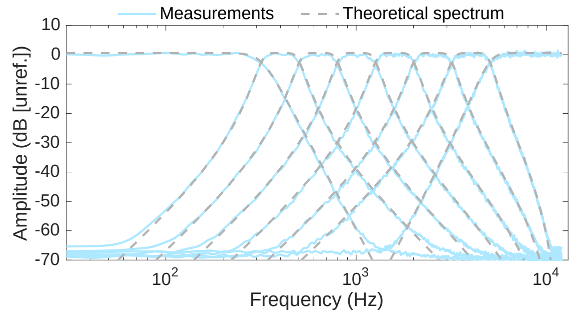

Figure 1: Frequency response of the filterbank : comparison between implemented TYMPAN filters responses (solid lines) and designed MATLAB filters (dashed lines)

Preliminary simulations involving the use of WDRC in two different coding environments seem promising. While features need to be adapted, and some work yet needs to be done for the two environments to be fully consistent, it has been shown that transfer between both platforms is possible without losing main characteristics.

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