An Analysis of a Smartphone-Based System for Learning Hearing Aid Personalization Settings and an Introduction of Deep Learning Lipreading Technology to Support the Hearing Impaired

(Technical Paper)

The Impact of Machine Learning/AI-Enabled Hearing Aids and Telehealth on the Audiologist-Patient Relationship

(STS Paper)

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Brandon Williams
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Technical Project Team Members
Brandon Williams

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Signature ____ Date ____11/21/2020____
Brandon Williams

Approved ____ Date ____11/21/2020____
Aaron Bloomfield, Department of Computer Science

Approved ____ Date _____11/21/2020____
Sean Ferguson, Department of Engineering and Society

Introduction

In the United States, hearing loss affects 34.25 million people, more than 10% of the population (Aldaz, G., Puria, S., & Leifer). For those who can afford hearing aid devices, the first step is being evaluated by a hearing care professional, or audiologist. The initial calibration, or fitting procedure, of the hearing aids is fitted to represent the average person without considering how different the hearing experience can be for a particular individual. The technical portion of this project analyzes cutting edge technology that takes advantage of the plethora of adjustable hearing aid parameters through machine learning and IoT applications to create a personalized experience for the end-user. Additionally, the technical portion of this project aims to extend on this idea by introducing a lipreading tool that will allow users to also use translated lipreading text to supplement their hearing. This research raised the question of how automation and telehealth for remote care will affect the relationships between audiologists and patients in the hearing care space. The STS research will take a deeper dive into how hearing care professionals and patients will both have to adjust to these novel technologies in order to continue fostering a healthy relationship built on trust and transparent communication.

Technical Prospectus

In 2018, hearing aid unit sales in the United States topped 3.97 million, a 5.3% increase over the 3.53 million units sold in 2017 (Karl). Of hearing aid companies that owned a significant share of the US hearing aid market in 2018, only WIDEX, at a 7% market share (US Hearing Aid Market), offered advanced machine learning technology in real time. Hearing aids powered by artificial intelligence has potential to give hearing aid end-users an unprecedented personalized sound experience by adjusting one of many amplifiable parameters. While “trainable” hearing aids have been around since 2006, there are two major challenges that we can classify as having “limited” the effectiveness of machine learning in hearing aids for end-users:

1) Technologically adapting to the growing complexity of the (dynamic) fitting procedure of the wide array of adjustable auditory parameters

2) Control of preferred settings when listening intentions for end-users vary in different sound environments

The shortcomings that stem from challenge 1 limited learning in hearing aids given that a typical hearing aid has limited sensor inputs, a restricted user interface, and reduced processing power preventing the implementation of more advanced machine learning algorithms (Aldaz, G., Puria, S., & Leifer). If there are thousands of different hearing aid parameters that can be adjusted, and you wanted to compare whether a client thinks “Sound A” is better than “Sound B” on a typical hearing aid, it would take nearly 2,500,000 comparisons to get through all the parameters! (Will machine learning in hearing aids make your job better?). Listening intention, as mentioned in challenge 2, is defined as the decision made by an individual about where they would like to focus their auditory attention in a specific environment at a given moment in time (Wendy Switalski, & James Martin).

In 2020, WIDEX became the first hearing aid manufacturer to pioneer a real-time AI solution that learns how users prefer various listening environments and provide solutions to both challenges 1 and 2. My thesis will involve performing a great deal of analysis on existing research of WIDEX’s real-time machine learning product, SoundSense Learn. SoundSense Learn solves the problem through a smartphone-based application that samples enough possible settings to adjust the user's preference for a given listening situation. Optimization is obtained by querying users' preferences within a mobile application through a series of A/B listening comparisons. Additionally, data is collected from over 40,000 hearing aid wearers that shares anonymized data with a cloud-based AI system (Kim, S). SoundSense Learn manages three acoustic parameters—low, mid, and high frequencies—which can be set to 13 different levels, resulting in more than 2000 possible settings. By introducing the smartphone as part of a hearing system, we gain new access to processing power that will allow more powerful machine learning algorithms to be run, leverage human computer interaction to extract preferred settings from users, and draw data from other user settings stored in the cloud to more precisely tailor the hearing aids to one's surroundings.

During the Spring 2020 semester, I will conduct a deep exploration into WIDEX's existing research on real-time smart-phone based machine learning applications in hearing aids, specifically the SoundSense Learn tool that can reach the optimal setting in 20 interactive steps with a human. By closely examining the human computer interaction, IoT, and machine learning components associated with a smartphone-based machine learning hearing aid system, I am hoping to theorize on its implications on hearing aid end-users. In partnership with Michael Tease, a former executive at WIDEX and a current executive at Starkey Technologies, another leading AI-based hearing aid manufacturer, it is my intention to gain more insight into how WIDEX leveraged the power of data from the Widex Cloud, where anonymized data from hearing aid end-users is leveraged to fine-tune existing machine learning algorithms.

In addition to an analysis of existing research on machine learning and the cloud computing implications of a smartphone-based hearing system, I plan to introduce a prototype that extends upon this idea into an area not yet fully exploited—deep learning applications in lip reading. There are several open-source codebases that implement a solution for translating lip reading to text. For example, Cross Audio-Visual Recognition using 3D Convolutional Neural Networks (Torfi, A., Iranmanesh, S. M., Nasrabadi, N., & Dawson, J.) uses a tensorflow-based python model to find the correspondence between audio and visual streams, as pictured below:

Figure 1. Processing pipeline

Audio-visual recognition (AVR) has been considered a solution for speech recognition tasks for when the audio is corrupted by leveraging extracted information from one modality (visual) to improve the recognition ability of the other modality by complementing the missing information (audio). This is a technique that the hearing-impaired use by supplementing their "corrupted" hearing with speechreading (lipreading) in order to piece together context. It is my plan to build out a tool that allows hearing aid end-users to wear a camera, send its live video feed data to a deep learning lipreading model, and send its translated output to be displayed as part of a mobile application for the hearing aid end-user to use in conjunction with "trainable" hearing aids.

STS Prospectus

The introduction of machine learning and AI-enabled hearing aids offers end-users an unprecedented level of control over their listening intentions by interacting with smartphone-based applications to adjust hearing settings in different environments without dependence on a hearing care professional, or audiologist. In 2020, a hearing aid satisfaction study was conducted by WIDEX in 9 countries to gauge overall satisfaction with the company's EVOKE SoundSense Learn hearing aids versus their own non-WIDEX hearing aids. Over 94% of participants prefer WIDEX EVOKE in noise over their own non-WIDEX hearing aids, strongly suggesting that end-users may be interested in making the transition to a more automated and personalized hearing experience (Hearing aid ratings). Long-term goals for this topic will involve theorizing how audiologist-patient behavior will evolve as the hearing aid industry begins to move towards automation.

Historically, health care professionals have driven the hearing aid fitting process with little or no participation from the end-user. The initial audiological assessment involves choosing a fitting formula derived from theoretical knowledge and experimental data to best suit an idealized "average" person, but this fails to address how hearing loss is an individual experience (Aldaz, G., Puria, S., & Leifer). Often times, hearing aids don't behave as expected, requiring multiple visits to the audiologist to fine-tune parameters correctly, which is an added source of frustration for hearing aid end-users in trying to gain control over their hearing. Previously, a hearing aid end-user would have to try to remember all of the details of a difficult learning situation so that they could explain it to their hearing healthcare professional at a later point, which is incredibly difficult.

These reasons motivated the development of WIDEX's EVOKE SoundSense Learn hearing aid system, which introduced real-time machine learning in a mobile application that guides patients to the best possible hearing experience in challenging situations. As an audiologist, this raises the internal conflict of sacrificing your own future job safety in favor of a stronger hearing solution for your patient. However, these leading machine-learning hearing aid manufacturers have marketed these products to audiologists as a novel new methodology for providing cutting-edge care to their patients to "make their jobs easier", not to eliminate them. This can take the form of telehealth, also offered by WIDEX, which allows for audiologists to counsel their patients and make hearing aid adjustments from a remote setting. While I have battled hearing loss since the age of 2 years old, it is important to realize that my experience is rare and does not represent the greater hard-of-hearing population, whose average age greatly exceeds mine. Recognizing that my age and studies introduce a bias that likely makes me more receptive to AI-enabled hearing aids and telehealth services, we will walk through and discuss a whitepaper that investigates the receptibility of older adults to using telehealth as a complement to in-person care amidst the COVID-19 pandemic. A recent nationwide survey of 2,000 adults found that 42% of adults have used telehealth services since the beginning of the pandemic and 82% of this select group enjoy using telehealth services (REMOTE CARE WSA WhitePaper). Again, as mentioned previously, it is not easy to generalize these results to the population of people with hearing loss. A total of 800 individuals were surveyed by WS Audiology with a median age of 79 years old and the following results were gathered (REMOTE CARE WSA WhitePaper):

1) 75% sheltered in place during the pandemic

2) 87% report difficulty with communication as a result of social distancing measures (masks completely remove ability to lipread)

3) 40% rank fitting and fine-tuning by a hearing care professional as most valued to them and 30% rank their hearing care professional being an expert as most valued to them

4) 53% have no experience with telehealth services but 27% have used telehealth services for the first time since the pandemic started

5) 66% will return for in-person visits when social distancing guidelines are removed while 33% will continue with remote care

These results, in combination with the baby boomer population approaching old age, actually suggests that audiologists will remain in-demand and just as critical to patient success. The first 30 to 60 days of a patient's experience with hearing aids are critical to long-term success, and this older demographic will continue to rely on hearing care professionals for routine adjustments as well as technical guidance as this COVID-19 susceptible demographic begins to rely more on remote care opportunities.

These tools of analysis will be critical in assessing how the dynamics of the audiologist-patient relationship will change in response to both advances in machine learning and AI within hearing aids, telehealth services, and the COVID-19 pandemic, considering the average age of > 66 years old for hearing aid end-users. My intended objectives will involve understanding the training methods that audiologists will have to undergo in order to achieve mastery of the evolution of hearing aids as well as how they will enable the older population of hearing aid end-users to achieve personalized hearing through telehealth services and smart-phone based machine learning tools. The essential stakeholders in this framework include audiologists, or hearing care professionals, hearing aid end-users, and hearing aid dispensers. To locate more information, I will be in contact with Michael Tease, former WIDEX executive and current Starkey Technologies executive, to gain insight into trends that are more difficult to find on public forums. Hearing technology as evolved, and we must evolve with it. Hearing care professionals will not be replaced by technology, but they must learn to master technology to keep pace with the industry and keep patients satisfied.

Next Steps

The common theme across both my technical and STS research projects involves an analysis of machine learning and AI in hearing systems as well as IoT applications that exchange video and audio information across different devices and systems. The analysis of existing research of machine learning and AI in hearing systems will require a deeper investigation into the procedures that went into its development at the lower-level. The project element of the technical portion will involve designing and implementing a series of services that allow a deep learning lipreading model, a live video feed, and mobile application to “talk” to each other. In the short-term, I will investigate open-source deep learning technologies that can feasibly be integrated into a system that communicates with a mobile application. A likely limitation of this is that the lipreading translations sent to the mobile application will not be in real-time as computer vision models require an extraordinary amount of processing power that goes beyond the capabilities of my computer’s hardware. In regards to the STS research, I will continue to research case studies and surveys of the hard-of-hearing demographic that has had experience with telehealth and the implications these results may have on the future of audiologist-patient relationships.

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