Audemo: A Web-Based Application for Simulating Auditory Perception in Individuals with Impaired Hearing

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Background

Hearing loss affects 432 million adults and 34 million children worldwide. Hearing loss may result from ageing, exposure to loud noise, genetic causes, complications at birth, certain infections, and use of particular drugs.[1] The degree of hearing loss is determined by an audiogram, a graph of the intensity in decibels (dB) required for an individual to hear sound at a particular frequency (Hz), shown in Figure 1. However, this does not capture the whole story. Speech is one of the most complex sounds we must listen to and impaired hearing resolution makes it hard to separate sounds and pick words apart from each other to understand sentences. With speech intelligibility issues, you may hear the sounds but not understand what is being said, so simply speaking louder does not resolve this issue. This difficulty, combined with a lack of awareness, creates communication issues between hearing-impaired individuals and their friends, loved ones, and employers.

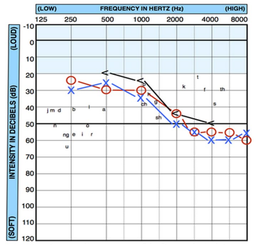


Figure 1. Audiogram of left and right ear.

Problem

Hearing loss is a complex, dynamic process that is unique to the individual, and therefore, it is very difficult for hearing-impaired individuals to explain to others what they can and cannot hear and it is equally as difficult for normal hearing individuals to understand what it is like. Hearing loss has been shown to negatively impact physical and mental health, perceptions of mental acuity, social skills, relationships, self-esteem, and work and school performance.[2] It is important for hearing-impaired individuals to be able to explain their auditory perception to others to help resolve these issues. Current hearing loss simulators, shown in Figures 2-3, are for clinical use only or are limited to demonstrating broad categories of hearing loss, and therefore, are not accurate for individual cases.

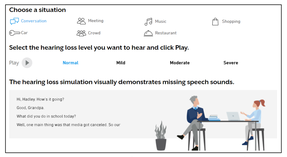


Figure 2. www.starkey.com/hearing-loss-simulator/simulator

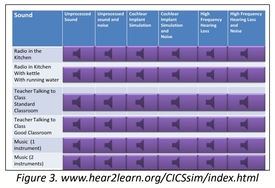


Figure 3. www.hear2learn.org/CICSsim/index.html

Need Statement

An easily accessible, customizable hearing impairment simulator to promote self-advocacy among individuals with impaired hearing by providing a tool to aid them in explaining their auditory perception to individuals with normal hearing.

Design Constraints

- Intuitive and simple to use
- Compatible with technologies owned and used by most people
- Free version with core functionality
- Compliant with web content accessibility guidelines (WCAG 2.0)
- Accurate within ±10 dB
- Minimize barriers to deployment and implementation
- Deadline: April 29th, 2020
- Budget: $1,000

Engineering Design

Overview: The simulator is based on a model of the auditory system that uses the user's audiogram data and subjective score of speech intelligibility problems to accurately represent their hearing impairment. As seen in Figure 4, the user can then upload any sound recording and the simulation will output the filtered, modified sound representative of how it is perceived by the user.

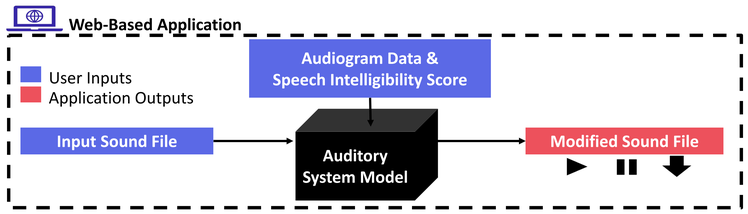


Figure 4.Overview of the design concept.

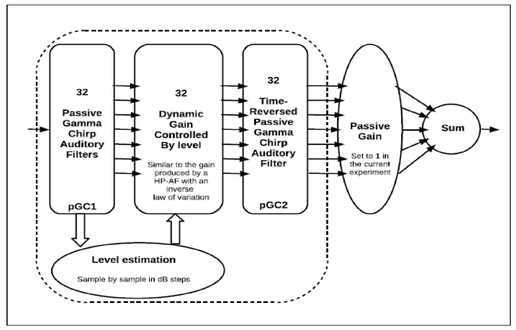


Figure 5. Comprehensive gammachirp filter used in the auditory system model.[3]

Back-end design/development involved:

- Flask application
- User authentication and security
- Server specifications
- SQL database integration to store user data
- Model integration and adaptation to accept the user inputs and to play/download transformed sound
- All code developed by the team was uploaded to a virtual repository on GitHub and can be accessed at **https://github.com/nacastroprice/hlsapp**.

Auditory System Model: This model is based on the comprehensive GammaChirp filter, shown in Figure 5, which is used to extract level-dependent filter shapes based on the user's compression loss which we represent here as the speech intelligibility score. The simulator acts as an inverse compressor in each frequency band to mimic the loss of compression experienced by hearing impaired individuals.

1) The input signal is filtered into 32 bands using a bank of passive GammaChirp (pGC) filters.
2) The dB level at the output of each pGC is estimated.
3) The level is used to control the center frequency of a high-pass asymmetry function (HP-AF) that represents the active mechanism in that filter band.
4) To cancel the natural compression of the filter bank, the hearing loss simulator applies a second version of the active mechanism described in reverse.
5) Lastly, the input audiogram is used to adjust for the users specific elevated thresholds and the sound is resynthesized.

The model was developed in Python by Samuel Garcia and made open-source on GitHub[4], and is an adaptation of the original model by Irino and Patterson et al.

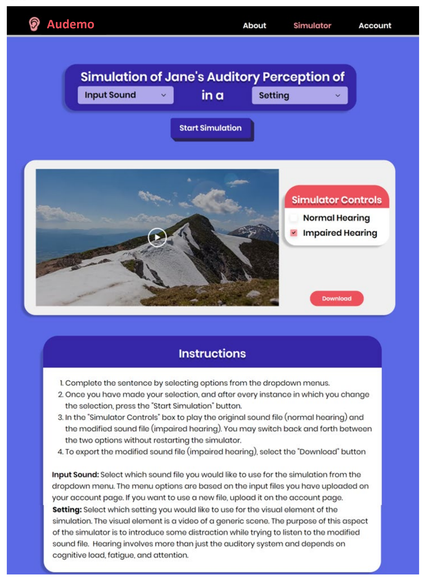
User interface was prototyped using Wix.com and is shown in the Final Design. Front-end development involved Bootstrap and Flask frameworks.

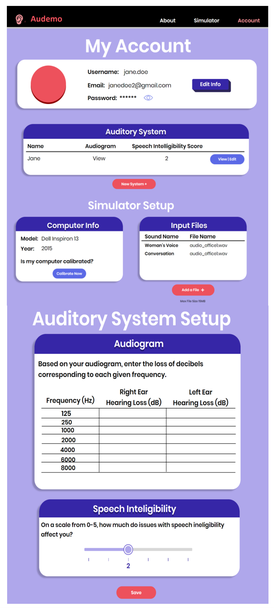
Final Design

Audemo is a web-based application that hosts a customized simulation of auditory perception in individuals with impaired hearing. The simulation tool is personalized to the user based on their audiogram data and speech intelligibility score. Users can create an account to save their data, so the simulator is ready-to-go for quick and easy demonstrations. The user interface prototype is shown below. The functioning application can be downloaded from GitHub.

Functioning App via GitHub:

UI Prototype via Wix:

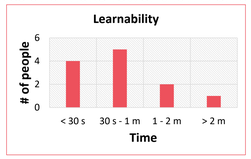


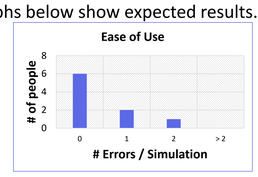


Verification & Validation

Verification

Usability testing via direct observation to ensure the application is intuitive and simple- users should be able to learn how to use the application in less than 2 minutes and make fewer than 2 errors. Graphs below show expected results.





Accessibility testing via direct use. Verify the application can run on the most popularly used operating systems and browsers.

Operating Systems	Browsers
Windows v.8-v.10	Chrome v.76.0
Mac OS 10.6-10.11	Firefox v.68.0
	Safari 12.0

Verify standards are met via code review and direct use of the application with accommodative software (i.e. screen readers used by visually impaired individuals).

Standard	Purpose
NIST 800-53	Database Security and Privacy
ISO IEC 27034	Application Security
WCAG 2.0	Web Content Accessibility

Validation

Unit testing via capacity simulation to ensure the performance requirements are met.

Performance Requirements
• 500 concurrent users on the website
• 5 users running the simulation at the same time

User testing via feedback surveys to ensure the need is being met and to gather data to guide future improvements. The user would be prompted to complete the online survey after using the simulator. Google Forms

Example Questions	Response Type
Impaired Hearing	Strongly disagree
• I feel empowered to advocate for myself.	Disagree
• Audemo aids in explaining my auditory perception to individuals with normal hearing.	Neutral
• Audemo accurately represents my unique hearing impairment.	Agree
Normal Hearing	Strongly agree
• I have a better understanding of his/her hearing impairment.	
• I want to work with him/her to develop better communication.	
Both	Short answer text
• Did you use headphones or your computer speakers?	
• What features would you like to see in the future?	

Future Work

Due to the COVID-19 pandemic, we were unable to deliver the project in the desired state. The work required to do so is described below. The current application is open-source, documented, and can be accessed and downloaded on GitHub. This makes it easy for future work by any party to be completed.

- Transform prototype to improve UI/UX
- Transfer application from local server to production server
- Perform verification and validation testing
- Create additional page for resources and communication tips
- Expand user inputs/outputs to include video recordings

Acknowledgements

Client: Michael Papp, AL Dept of Rehab
Faculty Mentors: Dr. Alan Eberhardt, Dr. Joel Dobbs, Dr. Dale Feldman, Dr. Abi Yildirim
Special thanks to Valerie DuBose (UAB DSS) and Tammy Blue for your insight and support!

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2. Hearing Loss Facts and Statistics. (n.d.). from the Hearing Loss Association of America.
3. M. Nagae, T. Irino, R. Nisimura, H. Kawahara and R. D. Patterson, "Hearing impairment simulator based on compressive gammachirp filter," Signal and Information Processing Association Annual Summit and Conference (APSIPA), 2014 Asia-Pacific, Siem Reap, 2014, pp. 1-4.
4. Garcia, Samuel. "Samuelgarcia/HearingLossSimulator." GitHub, github.com/samuelgarcia/HearingLossSimulator.