DEVELOPMENT OF AN AUDIOMETER PROGRAM FOR THE HEARING IMPAIRED

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To my parents and brother I would like to thank them for their encouragement and support they have given me.

Abstract

Majority of the audiometers at present use hardware devices which generate signals, store the data and may be integrated to a computer. The aim of this project is to develop an audiometer application which will generate user-specified signals on a personal computer. The values will be displayed to provide feedback to the hearing-impaired subject and the clinician. A time-frequency analysis of the audiometric patterns will be carried out using spectrogram, the frequencies-hearing levels graph of the right and left ears will be plotted together for comparison. Different techniques used in audiometry will be compared from both a clinical and signal processing point of view. The software is developed on Matlab development environment.

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Chapter 1 – Introduction

Audiology means the study of hearing and is a profession which assists those who have hearing impairments. Audiology is also a preventive health field, screening of newborns and young children and monitoring the hearing of those at risk of hearing loss. Audiology is a hearing health-care specialty, where audiologists, who work in private offices, clinics, medical offices and hospitals, are trained to diagnose and treat people with hearing and balance problems. It also involves counselling people to understand their problems and options and to avoid potential hearing problems in the future. In a broad sense audiology may be divided into two categories.

Experimental Audiology involves the study of the normal auditory system and its function in man and in animals and it also, relies on abnormalities of the human system to investigate normal function.

Clinical Audiology includes activities that are concerned with people who have hearing problems whether real or imagined, peripheral or central. In addition to the evaluation of hearing loss and the rehabilitation of individuals with hearing problems, clinical research is a vital part of clinical audiology since this improves the future understanding, identification and treatment of hearing disorders.

Treatment for deafness can vary from the fitting of an electronic hearing aid to major surgery, depending on the origin of the problem. In almost every case an audiometer is used to discover the magnitude of the hearing loss and to assist in the diagnosis of the type of deafness. Audiologists diagnose and treat hearing problems, including balance function and disorders through modern ear ware, including programmable and digital hearing aids. They develop and implement prevention, screening and early detection programs, recommend hearing protection in industrial, military, travel, music, and other settings. They also provide training in lip reading and understanding sounds.

Chapter 2 – Literature Review

2.1 Anatomy and Physiology of the Ear

The ear is divided into three anatomical regions: the external ear, the middle ear, and the inner ear (Figure 1). The external ear, the visible portion of the ear, collects and directs sound waves toward the middle ear. Structures of the middle ear collect sound waves and transmit them to an appropriate portion of the inner ear, which contains the sensory organs for hearing and equilibrium.

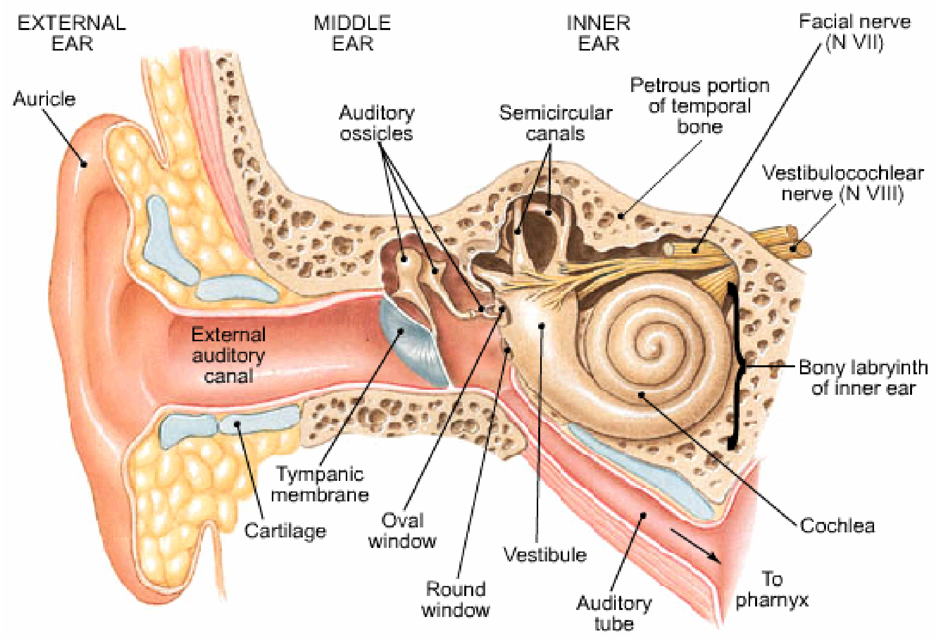


Figure 1 The Anatomy of the Ear - The boundaries separating the three regions of the ear (external, middle, and inner) are roughly marked by the dashed lines. (Fundamentals of Anatomy & Physiology - Prentice-Hall, Inc.)

2.1.1 The External Ear

The external ear includes the fleshy flap and cartilaginous auricle, or pinna, which surrounds the external auditory canal, or ear canal. The auricle protects the opening of the canal and provides directional sensitivity to the ear. Sounds coming from behind the head are blocked by the auricle; sounds coming from the side or front are collected and channeled into the ear canal.

The ear canal is a passageway that ends at the tympanic membrane, also called the tympanum or eardrum. The tympanic membrane is a thin, semitransparent sheet that separates the external ear from the middle ear (Figure 1).

The auricle and the narrow ear canal provide some protection from accidental injury to the tympanic membrane. Ceruminous glands, integumentary glands along the external auditory canal, secrete a waxy material that helps deny access to foreign objects or insects, as do many small, outwardly projecting hairs. The waxy secretion of the ceruminous glands, called cerumen, slows the growth of microorganisms in the ear canal and reduces the chances of infection.

2.1.2 The Middle Ear

The middle ear is filled with air and is separated from the external auditory canal by the tympanic membrane, but communicates with the nasopharynx through the auditory tube and with the mastoid air cells through a number of small connections (Figures 1 and 2a). The auditory tube is about 4 cm long and consists of two portions. The portion near the connection to the middle ear is relatively narrow and is supported by cartilage. The portion near the opening into the nasopharynx is relatively broad and funnel-shaped. The auditory tube permits the equalization of pressures inside and outside the tympanic membrane. It also allows microorganisms to travel from the nasopharynx into the middle ear causing infection.

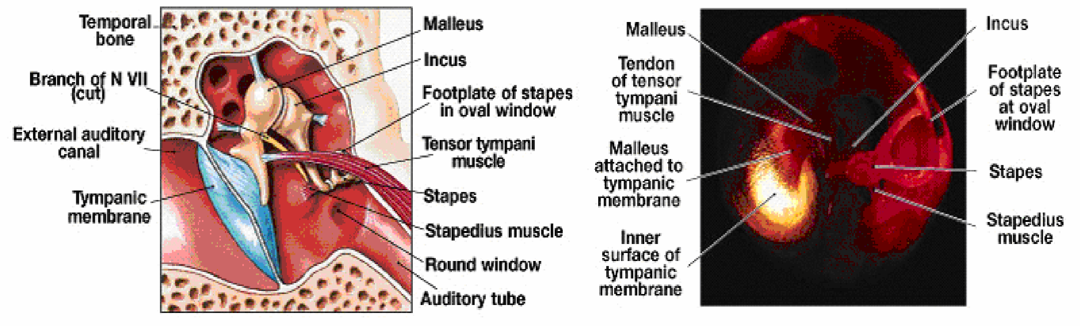


Figure 2 The Middle Ear. (a) The structures of the middle ear. (b) The tympanic membrane and auditory ossicles. (Fundamentals of Anatomy & Physiology - Prentice-Hall, Inc.)

The middle ear contains three tiny ear bones, collectively called auditory ossicles. The ear bones connect the tympanic membrane with one of the receptor complexes of the inner ear (Figures 1 and 2). The three auditory ossicles are the malleus, the incus, and the stapes. The malleus attaches at three points to the interior surface of the tympanic membrane. The incus, the middle ossicle, attaches the malleus to the stapes, the inner ossicle. The edges of the base of the stapes are bound to the edges of the oval window, an opening in the bone that surrounds the inner ear.

Vibration of the tympanic membrane converts arriving sound waves into mechanical movements. The auditory ossicles act as levers that conduct those vibrations to the inner ear. The ossicles are connected in such a way that an in–out movement of the tympanic membrane produces a rocking motion of the stapes. The tympanic membrane is 22 times larger and heavier than the oval window, so a 1-µm movement of the tympanic membrane produces a 22-µm deflection of the base of the stapes. Thus, the amount of movement increases markedly from tympanic membrane to oval window.

Due to this amplification occurs, one can hear very faint sounds. When exposed to very loud noises the degree of amplification can be a problem. In the middle ear, two small muscles protect the tympanic membrane and ossicles from violent movements under very noisy conditions:

1. The tensor tympani muscle is a short ribbon of muscle whose origin is the petrous portion of the temporal bone and the auditory tube and whose insertion is on the "handle" of the malleus. When the tensor tympani contracts, the malleus is pulled medially, stiffening the tympanic membrane. This increased stiffness reduces the amount of possible movement. The tensor tympani muscle is innervated by motor fibers of the mandibular branch of the trigeminal nerve (N V).
2. The stapedius muscle, innervated by the facial nerve (N VII), originates from the posterior wall of the middle ear and inserts on the stapes. Contraction of the stapedius pulls the stapes, reducing movement of the stapes at the oval window.

2.1.3 The Inner Ear

The senses of equilibrium and hearing are provided by the receptors of the inner ear (Figures 1 and 3). The receptors lie within a collection of fluid-filled tubes and chambers known as the membranous labyrinth. The membranous labyrinth contains endolymph, a fluid with electrolyte concentrations different from those of typical body fluids.

The bony labyrinth is a shell of dense bone that surrounds and protects the membranous labyrinth. Its inner contours closely follow the contours of the membranous labyrinth, and its outer walls are fused with the surrounding temporal bone. Between the bony and membranous labyrinths flows the perilymph, a liquid whose properties closely resemble those of cerebrospinal fluid.

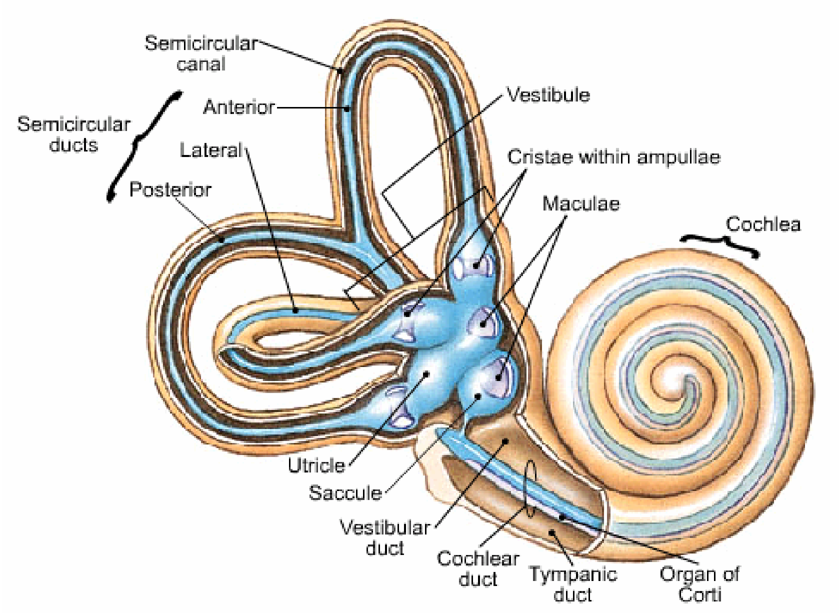


Figure 3 Inner Ear. The bony and membranous labyrinths. Areas of the membranous labyrinth containing sensory receptors (cristae, maculae, and the organ of Corti) are shown in purple. (Fundamentals of Anatomy & Physiology - Prentice-Hall, Inc.)

The bony labyrinth can be subdivided into the vestibule, three semicircular canals, and the cochlea (Figure 3). The vestibule consists of a pair of membranous sacs: the saccule and the utricle, or the sacculus and utriculus.

Receptors in the saccule and utricle provide sensations of gravity and linear acceleration.

The semicircular canals enclose slender semicircular ducts. Receptors in the semicircular ducts are stimulated by rotation of the head. The combination of vestibule and semicircular canals is called the vestibular complex. The fluid-filled chambers within the vestibule are broadly continuous with those of the semicircular canals.

The cochlea is a spiral-shaped, bony chamber that contains the cochlear duct of the membranous labyrinth. Receptors within the cochlear duct provide the sense of hearing. The cochlear duct is sandwiched between a pair of perilymph-filled chambers. The entire complex makes turns around a central bony hub. In sectional view, the spiral arrangement resembles a snail shell.

The walls of the bony labyrinth consist of dense bone everywhere except at two small areas near the base of the cochlear spiral (Figure 1). The round window is a thin, membranous partition that separates the perilymph of the cochlear chambers from the air spaces of the middle ear. Collagen fibers connect the bony margins of the opening known as the oval window to the base of the stapes. When a sound vibrates the tympanic membrane, the movements are conducted to the stapes by the other auditory ossicles. Movement of the stapes ultimately leads to the stimulation of receptors in the cochlear duct, making sound audible.

2.1.4 Hearing

The receptors responsible for auditory sensations are hair cells which are found within the cochlear duct and the organization of the surrounding accessory structures shield them from stimuli other than sound.

In conveying vibrations from the tympanic membrane to the oval window, the auditory ossicles convert pressure fluctuations in air to pressure fluctuations in the perilymph of the cochlea. These fluctuations stimulate hair cells along the cochlear spiral. The frequency of the perceived sound is determined by which part of the cochlear duct is stimulated. The intensity of the perceived sound is determined by how many of the hair cells at that location are stimulated.

2.2 Disorders in the Ear

By considering the appropriate case history or physical findings, various disorders may affect the ear or central nervous system (CNS). These diseases may be congenital or acquired pathologies.

2.2.1 Disorders in the External Ear

Congenital abnormalities of the external ear may include malformation of the auricle, such as microtia, or atresia of the external auditory canal. Conductive hearing loss seen in association with incomplete development of the mandible may suggest Treacher Collins' syndrome, which is usually accompanied by deformation of the external ear and meatal atresia, as well as underlying ossicular deformity, which is due to the arrest in development of the first branchial groove and arch in the second month of fetal life (Tewfik et al., 1997).

Acquired abnormalities of the external ear may include External Auditory Canal Obstruction – obstruction of the external auditory canal by cerumen impaction or various foreign bodies, Otitis Externa – Inflammation of the auricle and the external auditory canal by bacterial or fungal infection or dermatitis, or Bony growths of the external canal – Ommon forms of bony growths are osteomas and exostoses.

A conductive hearing loss is caused by problems occurring in the outer or middle ear. It is called "conductive" because something reduces or stops the conduction of sound from reaching the inner ear or cochlea, where sound is sent to the brain via the hearing nerve. Holes in the ear drum, a middle ear infection, wax in the ear canal, a missing ear canal, disease, etc. are examples of a conductive hearing loss.

Most often a conductive hearing loss is medically or surgically treatable through a physician or specialist (Ear Nose and Throat physician). In the event a specialist deems the conductive problem untreatable, a special type of hearing aid may be appropriate to help an individual to hear better. Special bone conduction hearing aids transmit sound to the cochlea through vibration, however, these devices require that a sensorineural (inner ear) hearing loss is not present at the same time or is at least a minimal. A standard assessment performed by an audiologist may determine candidacy for such a device.

2.2.2 Disorders in the Middle Ear

Congenital abnormalities of the middle ear are found usually with congenital atresia. Anomalies like fusion of the incus and malleus or stapes deformation, or compete absence of ossicles are possible.

Acquired abnormalities of the middle ear may include Serous Otitis Media, Acute Otitis Media, Chronic Otitis Media and Tympanic Membrane Perforation.

2.2.3 Disorders in the Inner Ear

Congenital abnormalities of the middle ear is defined as the hearing loss that occurs secondary to perinatal infection or developmental abnormality which may be due to the malformation of the inner ear. Various hereditary disorders are related to genetic abnormalities at the chromosomal level which may be transmitted in dominant or recessive patterns.

Acquired abnormalities of the inner ear may include Noise-Induced Hearing Loss, Drug-Induced Hearing Loss, Presbycusis, Infectious Hearing Loss and Ménière’s Disease.

A sensorineural hearing loss occurs in the inner ear and is caused by damage sustained to the cochlea or hearing nerve. Nerve cell damage can be caused by noise exposure (music, machinery, etc.), aging, meningitis, strong medications (antibiotics, chemotherapy, diuretics through intravenous or IV, etc.), maternal diseases (such as rubella), heredity, chronic ear infections, head injury, to name a few. Sensorineural hearing losses are typically irreversible (or permanent) and may require the use of hearing aids depending on the cause of the hearing impairment and its severity.

2.2.4 Degrees of Hearing Loss

The effects of hearing impairment can be staggering. Depending on the degree or configuration of a conductive and/or sensorineural hearing impairment, simple day to day tasks can be challenging. From simply understanding spoken communication to lack of speech and language development or social isolation, hearing is a sense that is taken for grated until we have lost normal functioning of our auditory system. An individual, who has acquired hearing loss, either through birth or disease or aging, etc., is not necessarily considered "deaf" but may be more appropriately termed "hearing impaired".

For children, "normal" hearing sensitivity and its corresponding threshold (lowest level of hearing) responses fall between 0-15 decibels (dB). An adult may be considered to have normal hearing sensitivity if their responses fall between 0-25dB. Therefore a "minimal" hearing impairment category is reserved for children only.

For children who sustain a "minimal" hearing impairment (16-25dB) that is left untreated, a mild auditory dysfunction may occur and result in speech and language deficits as some high pitched unvoiced consonants (s, f, t, etc.) may be missed. It also may result in "inattentive" behaviour. Based on their existing vocabulary and knowledge of the rules of spoken language, adults have the ability to conclude what was said even if the whole message was not received.

A "mild" hearing impairment (26-40dB) allows only for louder speech (voiced consonants and vowels) sounds to be heard, therefore causing the same inattention and more severe language and auditory dysfunction. Based on the missing elements of spoken language a hearing aid is most often recommended (if sensorineural in nature) for children and adults and most times is beneficial for oral communication and education. Speech therapy may also be required for children.

A "moderate to moderately severe" hearing impairment (41-70dB) will miss most speech sounds at regular conversational levels in quiet, and all speech sounds in the presence of background noise (e.g. classroom). Hearing aids are strongly recommended for sensorineural hearing impairments in children and adults. Assistive listening devices (FM, infrared devices, etc.) are common in the child’s classroom in addition to their amplification.

A "severe" hearing impairment (71-90dB) hears no speech sounds at regular conversational level in any situation. Hearing aids and assistive listening devices are necessary for the reason that severe speech and language problems occur and the noise in a regular classroom is too great for effective learning. A child may therefore require special classroom placement.

A "profound" hearing impairment (90dB and above) is the category usually reserved for the term "deaf" as most environmental sounds are not perceived (unaided). Depending on the individual and degree of hearing impairment a hearing aid may or may not be advantageous for speech and language reception and development. In the event an appropriate hearing aid fitting is deemed not beneficial the individual may be considered a potential candidate for a cochlear implant. Some individuals experience hearing loss as well as the inability to distinguish the small differences between similar sounds; therefore no amount of amplification will be sufficient for effective communication.

2.2.5 Configurations of Hearing Loss

The normal human ear can hear frequencies (or pitch) from 20Hz to 20,000Hz. When testing an individual’s hearing sensitivity, an audiologist will assess those frequencies that are most important for speech and language (or between 250-8000Hz) and find the lowest level of hearing (threshold) at each octave (and sometimes inter-octave) frequency. It is possible and common to have normal hearing in one range (e.g. low pitch) and a significant hearing loss in another (e.g. high pitch) range. These types of hearing losses can be ignored or go unidentified for a long time because the individual can hear but can’t understand at times, particularly in noise or people appear to be "mumbling".

A "sloping" configuration of hearing impairment means better hearing in the lower range than in the higher range and is probably the most common configuration. The most important frequencies for speech occur between 500-4000Hz and if the hearing loss is sustained only in the higher frequencies, the individual may perceive little difficulty.

A "flat" configuration means most or all of the frequencies were effected equally. However, a minimal to mild flat hearing loss may seem insignificant to the adult listener but may affect a child’s speech and language development by missing the high pitched unvoiced consonants. A moderate to severe flat hearing loss would be difficult to deny any hearing handicap.

A "rising" configuration means low frequencies are affected greater than the higher frequencies. As with the sloping configuration, a rising configuration will be difficult to identify as most consonants are found in the mid to high frequencies and the vowels and voiced consonants found in the low frequency range are spoken of louder volume and may still be perceived (although softly).

A "cookie-bite" or mid frequency hearing loss is less common and is most problematic (hearing and rehabilitation wise). More sophisticated, special hearing aids are available and are prescribed to accommodate the configuration and may be more expensive than a standard hearing aid.

2.3 Audiometer

An audiometer is an oscillator driving a pair of headphones and is calibrated in terms of frequency and acoustic output. Both frequency and output are adjusted over the audio-range. The instrument is also provided with a calibrated noise source and bone-conductor vibrator. The commonest type of audiometer produces pure tones at set frequencies and known amplitudes through headphones worn by the patient who is required to indicate which of the tones is heard. Variations exist which do not use headphones and the tones may be replaced by words which the patient is required to recognize and repeat.

2.3.1 Pure Tone Audiometer

A wave that involves one frequency of vibration is known as pure tone. Since it is used in routine tests, pure tone audiometer is more commonly used to determine hearing loss. It generates tones in octave steps from 125 Hz to 8000 Hz, where the range of the signal intensity is from -10 dB to +100 dB. A pure tone is the simplest type of auditory stimulus whose frequency and intensity can be specified with a high degree of precision. Measurements of frequencies made by speech audiometry are within the range 300 Hz to 3000 Hz. Due to high intensity level occupational noise, pure tone measurements at high frequencies provide a sensitive indicator of the effect of noise on the ear. A pure tone audiometer consists of an LC oscillator where the inductance and tuning capacitance of close tolerance have precise control on the frequency of oscillations. The required power levels are produced by the coupling of the oscillator to an output current amplifier. Earphones are used to present the signals acoustically.

2.3.2 Speech Audiometer

Speech audiometry tests may be used before prescribing hearing aids and determining the deterioration of speech understanding of patients. The subjective measure of the extent of a hearing defect can be obtained by the delivery of speech at a known sound pressure level and scoring the number of words correctly recognized. The speech is usually generated from a tape recording of the word lists played through an audiometer so that the sound level delivered can be changed to known levels for each part of the test. The level of co-operation of the patient is crucial to the correct interpretation of the result.

Chapter 3 – Audiometer Software Design

The main aim of the project is to build an Audiometer application for a personal computer using the Matlab development environment. The application generates frequencies, plays and displays a spectrogram of the frequency selected by the user. The application also stores a list of frequencies played and the hearing level at the appropriate ear. Most of the audiometers available are hardware based thus taking up space and tends to need servicing after a period of time. This application only requires a computer with a calibrated sound card and head-phones. Bugs found in the program can be isolated and a patch can be developed, without halting the system, thus reducing the cost from serving.

Initially, the audiometer program was to be developed using the Simulink package of Matlab. Since the package had built in block sets and further coding would become more complex and complicated. So, the audiometer program was developed in Matlab development environment. The Graphical User Interface (GUI) and the audiometer code were stored in two separate files. This was complicated, since the variables had to be passed between the codes. So finally, the GUI and the audiometer code were combined into one code.

The GUI being built using GUIDE (GUI Builder) initially consisted of a graph, radio buttons, slider, popup menu, and push buttons. On program execution, the ‘Right Ear’ option is set, the frequency selected is zero, the hearing level is at 0 dB and the spectrogram shows 0 Hz by default. Initialisation of the sinusoidal frequency f, the sampling frequency fs, where these are in radians per second, and the length of the sample N is done on the GUI initialisation. A vector containing all the time samples is generated using the equation

$$t = \left(2 * \Pi * [1:N]\right) \div fs$$

Then the sinusoidal samples is generated using the formula

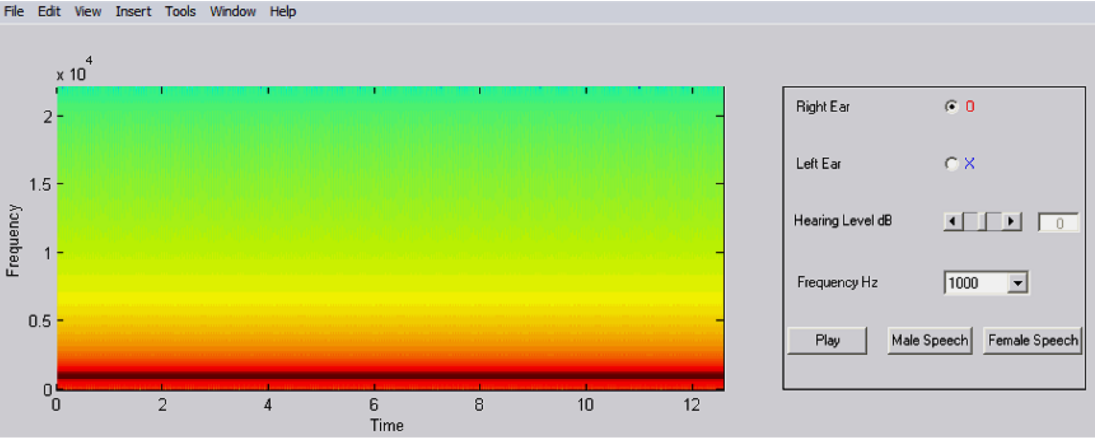
$$y = A * Cos(fs * t)$$

A is the amplitude given by the equation

$$A = 10\wedge(db/20)$$

where *db* is the selected decibel level. The decibel level can be increased or decreased according to the requirements.

The frequencies for duration of 1 to 2 seconds are stored in a matrix. When a frequency is selected, then the pointer points to that frequency in the matrix. According to the option of the ear selected, ‘Right Ear’ or ‘Left Ear’, the frequency is stored in ‘2XN’ Matrix, where one of the rows is the frequency while the other row is zeros. When the play push button is pressed, the selected frequency is played in the appropriate ear. Also, two wave files, male speech and female speech are read and stored in memory during the GUI initialisation. Male and female speech can be played in the same way as pure tone frequencies.


Right Ear ● O

Left Ear ○ X

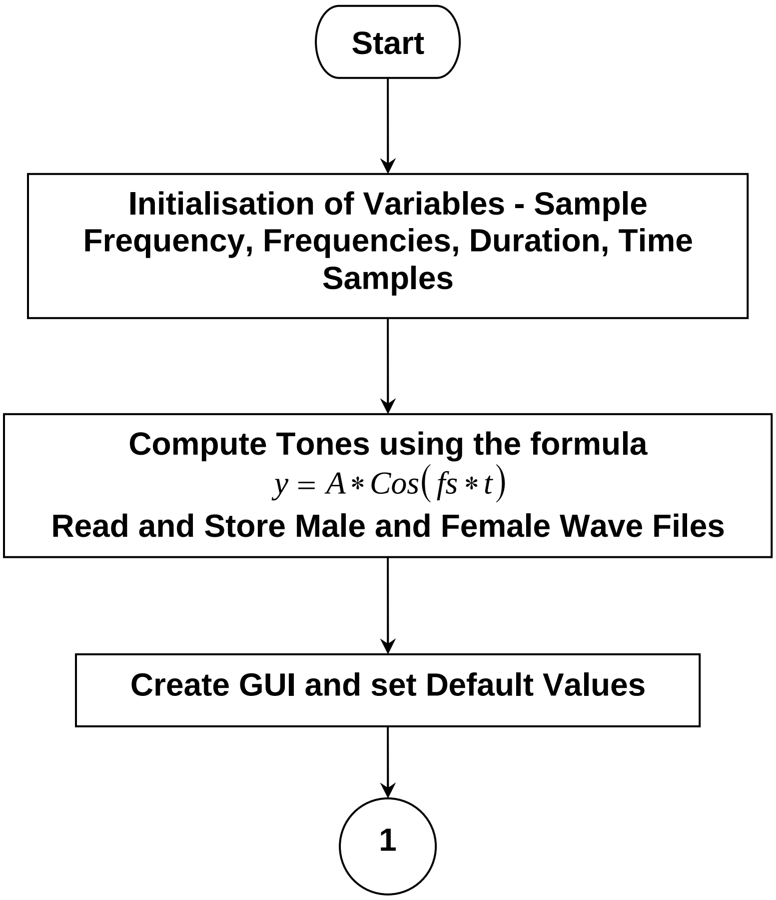
Hearing Level dB 0

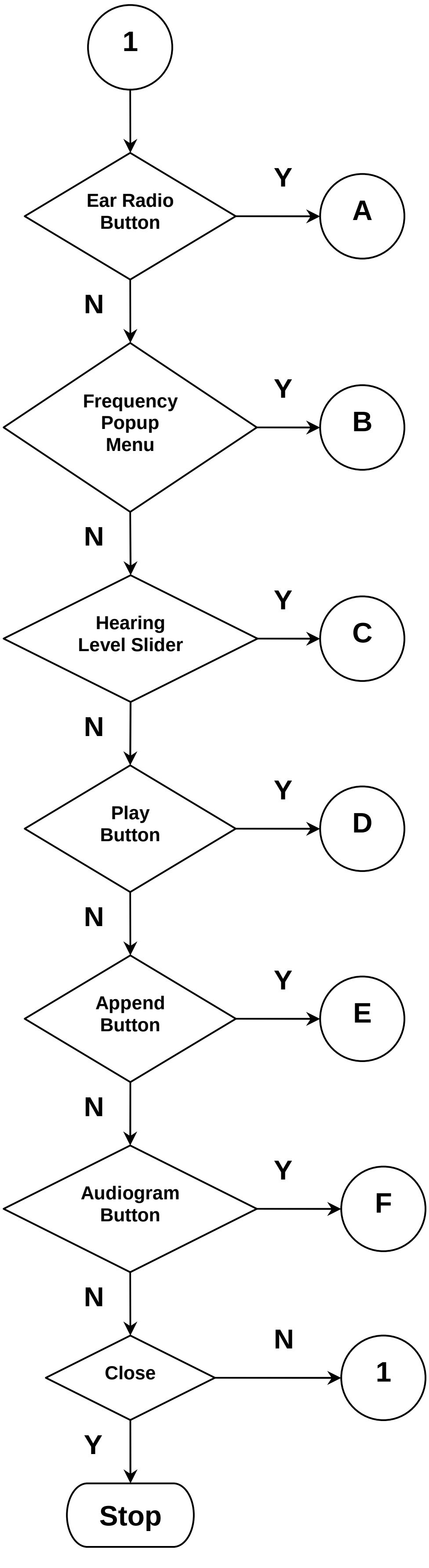
Frequency Hz 1000

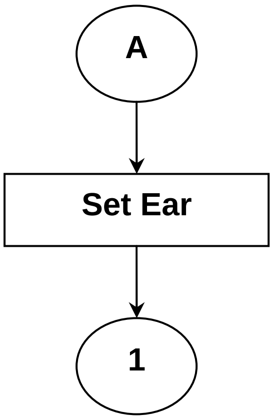
Figure 4 First Audiometer program created

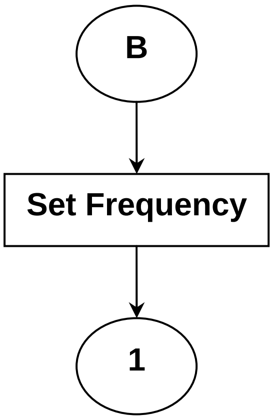
Later on a list box and pushbuttons were added for further functionality. The functionality included storing information about the frequency played, the hearing level and the selected ear in a list box by selecting the append push button. The remove pushbutton, deletes the unnecessary or unintended data from the list box. On using the ‘Audiogram’ push button, the data from the list box is stored into a matrix. Then, the hearing levels of the same frequencies of each ear are averaged. The frequencies are then sorted in ascending order, after which the frequencies and their appropriate hearing levels are separated on the basis of ear. The data for the ‘Right Ear’ and ‘Left Ear’ are stored in two different matrixes. The graph is plotted between ‘Frequency’ and ‘Hearing Level’ for both the ‘Right Ear’ and Left Ear’ simultaneously.

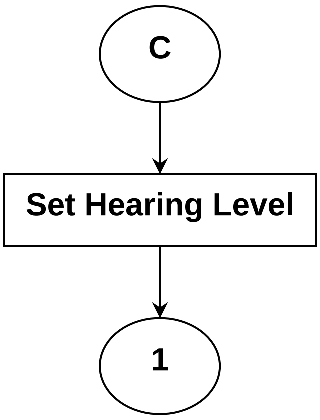
3.1 Flowchart

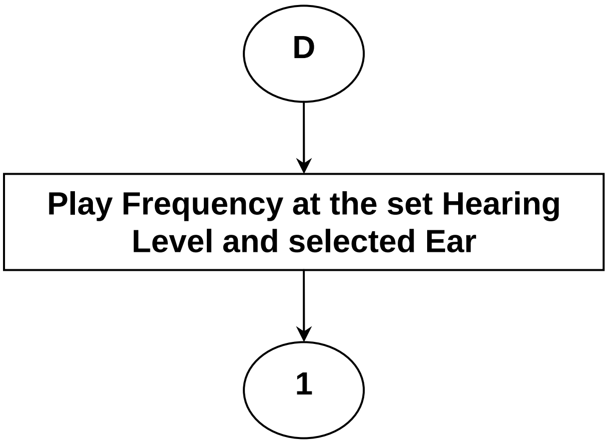


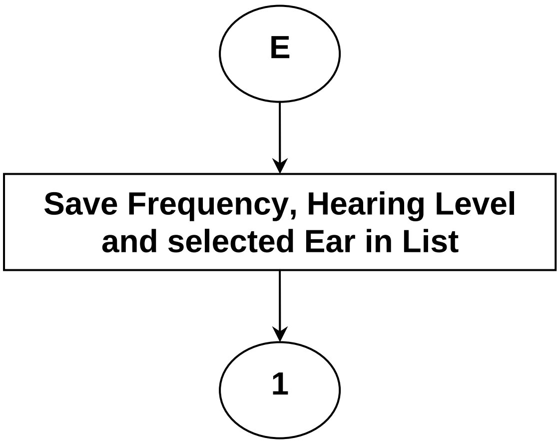

1
Ear Radio Button
Y
A
N
Frequency Popup Menu
Y
B
N
Hearing Level Slider
Y
C
N
Play Button
Y
D
N
Append Button
Y
E
N
Audiogram Button
Y
F
N
Close
N
1
Y
Stop

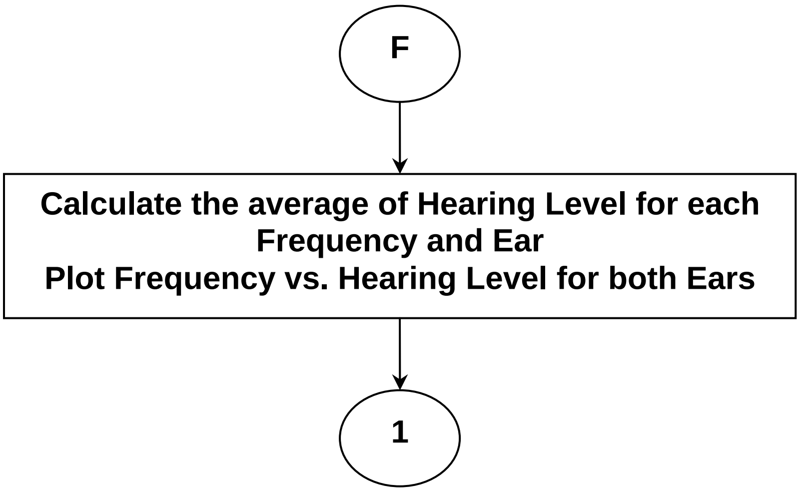

A
Set Ear
1


B
Set Frequency
1

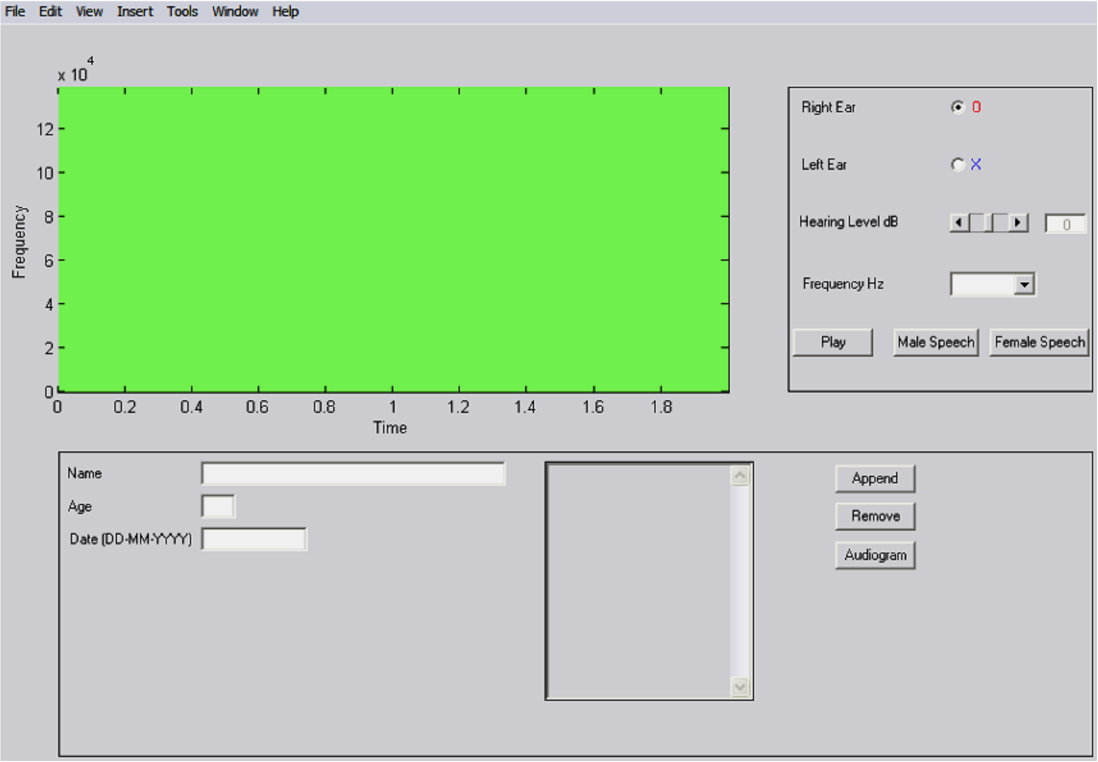

C
Set Hearing Level
1


D
Play Frequency at the set Hearing Level and selected Ear
1


E
Save Frequency, Hearing Level and selected Ear in List
1


F
Calculate the average of Hearing Level for each Frequency and Ear
Plot Frequency vs. Hearing Level for both Ears
1

Chapter 4 – Results



Right Ear ● O

Left Ear ○ X

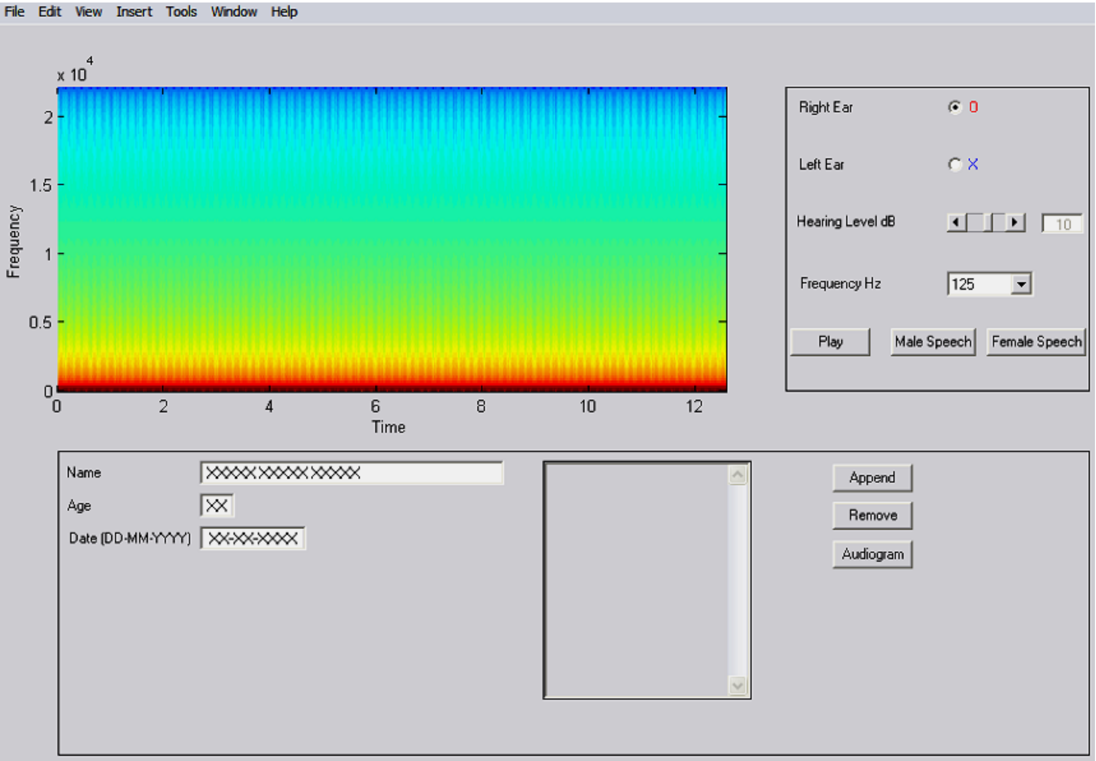
Hearing Level dB 0

Figure 5 Final Audiometer program

Procedure for using the Audiometer Program:

1. Select the better ear. If there is no difference, select the right ear.
2. Select the frequency, play the tone at 0 dB. If a hearing loss is suspected, keep increasing the intensity by 2 dB, until the patient responds. The test tone should last between one to two seconds.
3. After the patient initially responds, lower by 10 dB and present the tone. If the patient responds, lower by 10 dB and keep on lowering by 10 dB until the patient does not respond.
4. When the patient does not respond, increase in 2 dB increments until the patient responds.
5. Store the values by using the append push button. Repeat steps 3 and 4 until you obtain two to three ascending responses.
6. After testing 125 Hz, test 250, 500, 1000, 2000, 4000, 8000 Hz in the same ear. Additionally 750, 1500, 3000, 6000 Hz may also be tested.

7. Repeat steps 2 through 6 for the opposite ear.



Right Ear ● O

Left Ear ○ X

Hearing Level dB 10

Frequency Hz 125

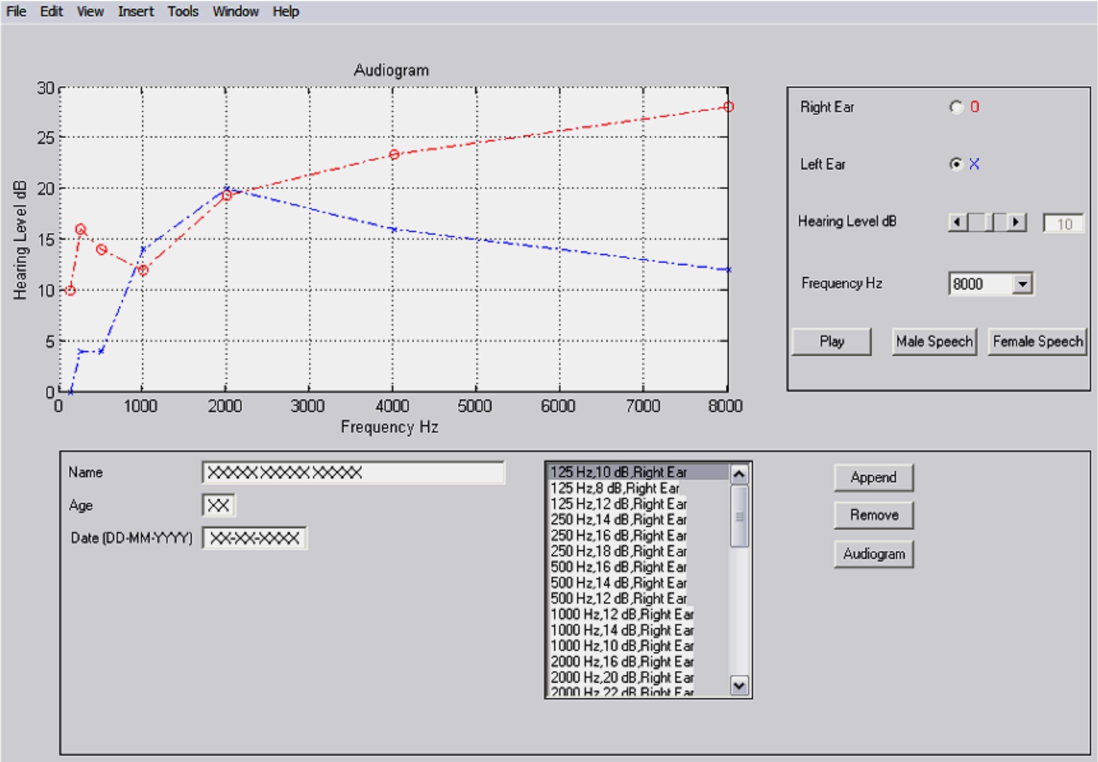
Name XXXXX XXXXX XXXXX

Age XX

Date (DD-MM-YYYY) XX-XX-XXXX

Figure 6 Example of the Audiometer program playing 125 Hz at 0 dB on the Right Ear

Threshold is defined as the lowest intensity where the patient responds to two to three ascending tones. After getting the list of values, the Audiogram is plotted by selecting the ‘Audiogram’ push button. The audiogram push button, plots the audiogram with the data stored in the list box, thus enabling in the comparison and study of the response of the frequencies at the appropriate hearing levels in the ‘Right Ear’ and ‘Left Ear’. The graph for the ‘Right Ear’ is plotted in red and the ‘Hearing Level’ at the tested ‘Frequencies’ is plotted with the symbol ‘O’. The graph for the ‘Left Ear’ is plotted in blue and the ‘Hearing Level’ at the tested ‘Frequencies’ is plotted with the symbol ‘X’. The graph shows the difference in the response levels of both ears. Male and Female speech can also be used to test the patient’s recognition of speech.



Right Ear ○ O

Left Ear ● X

Hearing Level dB 10

Frequency Hz 8000

Name XXXXX XXXXX XXXXX

Age XX

Date (DD-MM-YYYY) XX-XX-XXXX

125 Hz,10 dB,Right Ear
125 Hz,8 dB,Right Ear
125 Hz,12 dB,Right Ear
250 Hz,14 dB,Right Ear
250 Hz,16 dB,Right Ear
250 Hz,18 dB,Right Ear
500 Hz,16 dB,Right Ear
500 Hz,14 dB,Right Ear
500 Hz,12 dB,Right Ear
1000 Hz,12 dB,Right Ear
1000 Hz,14 dB,Right Ear
1000 Hz,10 dB,Right Ear
2000 Hz,16 dB,Right Ear
2000 Hz,20 dB,Right Ear
2000 Hz,22 dB,Right Ear

Figure 7 Example of the Audiometer program displaying the Audiogram

Chapter 5 – Conclusions & Future Work

The development of the software based pure-tone audiometer was successful. The system was however tested using a sound card that was not calibrated. Since the system was not calibrated it was difficult to determine the exact point of 0db. So, the tone played at 0 dB was not played at 0 dB in reality. To solve this problem it is recommended that the headphones be standardized using sound level calibrators. Calibrating the sound card requires artificial ears which can be used to set the normal sound card output to 0 dB.

The software based audiometer has the advantage that improvisations can be made faster and errors can also be rectified quickly. Once a standard procedure for testing and calibration is set up it would be possible to normalize the same across all hospitals and audiology centres. This would also allow portability of patient data, which can now be done very easily through the internet.

Being a software based audiometer there is huge scope for future enhancements in terms of its functionality. The program can be improved by improving the speech capabilities of the system, where the patient may have to identify certain phonemes in a word. The system can be improved further by incorporating multi-frequency generation and mixing. For tests that need require speech the system can be improved by adding a text to speech algorithm.

A major improvement would be to incorporate electric response audiometers (ERA) which detect whether an auditory stimulus has been received at the cochlea, the brain stem, the cortex, or in auditory reflex arcs as may be detected from the electromyogram of the post auricular muscle (PAM), sometimes called the crossed acoustic response.

On the front of patient information management the system can be improved by adding a database which will allow easy storage and retrieval of patient information. This would also allow tracking of patient history.

References

- Fundamentals of Anatomy & Physiology (Prentice-Hall, Inc.)
- Owens, F.J. (1993), *Signal Processing of Speech*, Macmillan
- Deller, J.R., Proakis, J.G., and Hanson, J.H. (1993), *Discrete-Time Processing of Speech Signals*, Macmillan
- http://www.thebrowns23.freeserve.co.uk/entries/AUDIOMETER.html
- Handbook of Clinical Audiology (Lippincott Williams &Wilkins)
- Handbook of Biomedical Instrumentation (Tata McGraw-Hill Publishing Company Limited)
- http://medizin.li/audiometer/
- http://www.esser.u-net.com/homeaudiometer.htm
- http://facstaff.uww.edu/bradleys/ohc/audiometry/page1.html
- http://www.microaud.com/earscaud.htm
- http://www.medcatalog.com/audiometer.htm
- http://www.dcs.shef.ac.uk/~martin/MAD/audiometer/audiometer.htm
- http://www.frye.com/products/audiometers/fa10_12.html
- http://www.ohnsolutions.com/audiometer%20calibrator%20acs.htm
- http://www.circuitcellar.com/PSOC2002/winners/h10.pdf
- http://www.dsptutor.freeuk.com/
- http://www.bksv.com/631.htm
- http://www.bdti.com/faq/

Appendix – Matlab Code

```
function varargout = Audiometer(varargin)
%The project is about building a PC based Audiometer. An Audiometer is a
%machine used to discover the magnitude of the hearing loss and to assist
%in the diagnosis of the type of deafness. This project is done as a final
%project for the MSc. Bioengineering by Anish Sam Philip, August 2003.

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @Audiometer_OpeningFcn, ...
                   'gui_OutputFcn',  @Audiometer_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin & isstr(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT



% --- Executes just before Audiometer is made visible.
function Audiometer_OpeningFcn(hObject, eventdata, handles, varargin)
% Choose default command line output for Audiometer
handles.output = hObject;
%All the variables are stored in User Data, and can be accessed when the
%User Data is called. To store data in User Data, the variables should
%linked to it. ud.fs stores the sampling frequency, ud.freqs stores an
```

```
%array of frequencies used for the program, ud.n stores the duration of the
%frequencies to be generated, ud.t stores the vector containing all the
%time samples, ud.f points to a frequency in the array ud.freqs, by default
%ud.f = 100, implies that no frequency is selected.
ud=get(gcf,'UserData');
ud.fs=2*pi*44100;
ud.freqs=[125 250 500 750 1000 1500 2000 3000 4000 6000 8000]*2*pi;
ud.n=round(2*ud.fs);%Increasing 2 will increase the duration.
ud.t=2*pi*[1:ud.n]/ud.fs;
ud.f=100;

%Precompute Tones
%ud.tones stores the sinusoidal samples, ud.male stores the male speech
%from the Male.wav and ud.female stores the female speech from the
%Female.wav. ud.tones is initialised into a 2D Matrix, then each sampled
%frequency is stored in rows.
ud.tones=zeros(length(ud.freqs),ud.n);
for f=1:length(ud.freqs)
    ud.tones(f,:)=cos(ud.freqs(f)*ud.t);
end
ud.male=wavread('male');
ud.female=wavread('female');

%Right Ear radio button is made active, the value of the Slider is
%displayed on a Text Box. ud.z is a zero Matrix with length of the first
%row of ud.tones. The spectrogram displays a zero Matrix on the graph.
set(handles.rightear,'Value',1);
set(handles.leftear,'Value',0);
set(handles.dblevel,'String',num2str(get(handles.level,'Value')));
ud.z=zeros(1,length(ud.tones(1,:)));
specgram(ud.z,[],ud.fs);
set(gcf,'UserData',ud);
% Update handles structure.
guidata(hObject, handles);
% UIWAIT makes Audiometer wait for user response (see UIRESUME)
```

```
% --- Outputs from this function are returned to the command line.
function varargout = Audiometer_OutputFcn(hObject, eventdata, handles)
% Get default command line output from handles structure
varargout{1} = handles.output;


% --- Executes on button press in rightear.
function rightear_Callback(hObject, eventdata, handles)
%Right Ear is Active.
set(handles.rightear,'Value',1);
set(handles.leftear,'Value',0);


% --- Executes on button press in leftear.
function leftear_Callback(hObject, eventdata, handles)
%Left Ear is Active.
set(handles.rightear,'Value',0);
set(handles.leftear,'Value',1);


% --- Executes on slider movement.
function level_Callback(hObject, eventdata, handles)
%Get the value of Slider and display it on the Text Box.
set(handles.dblevel,'String',num2str(get(handles.level,'Value')));
% Hints: get(hObject,'Value') returns position of slider
%        get(hObject,'Min') and get(hObject,'Max') to determine range of slider


% --- Executes on selection change in frequency.
function frequency_Callback(hObject, eventdata, handles)
%Get the Frequency selected.
val=get(hObject,'Value');
%Point to the row of the selected Frequency.
```

```
switch val
case 1
   ud=get(gcf,'UserData');
   ud.f=100;
   set(gcf,'UserData',ud);

case 2
   ud=get(gcf,'UserData');
   ud.f=1;
   set(gcf,'UserData',ud);

case 3
   ud=get(gcf,'UserData');
   ud.f=2;
   set(gcf,'UserData',ud);

case 4
   ud=get(gcf,'UserData');
   ud.f=3;
   set(gcf,'UserData',ud);

case 5
   ud=get(gcf,'UserData');
   ud.f=4;
   set(gcf,'UserData',ud);

case 6
   ud=get(gcf,'UserData');
   ud.f=5;
   set(gcf,'UserData',ud);

case 7
   ud=get(gcf,'UserData');
   ud.f=6;
   set(gcf,'UserData',ud);
```

```
case 8
   ud=get(gcf,'UserData');
   ud.f=7;
   set(gcf,'UserData',ud);

case 9
   ud=get(gcf,'UserData');
   ud.f=8;
   set(gcf,'UserData',ud);

case 10
   ud=get(gcf,'UserData');
   ud.f=9;
   set(gcf,'UserData',ud);

case 11
   ud=get(gcf,'UserData');
   ud.f=10;
   set(gcf,'UserData',ud);

case 12
   ud=get(gcf,'UserData');
   ud.f=11;
   set(gcf,'UserData',ud);
end
% Hints: contents = get(hObject,'String') returns frequency contents as cell array
%        contents{get(hObject,'Value')} returns selected item from frequency


% --- Executes on button press in play.
function play_Callback(hObject, eventdata, handles)
%The selected frequency gets multiplied with the amplitude from the level
%(Slider), and is stored in tone. According to the selected radio button,
%right or left, a 2D Matrix is made with one row as zeros and the other row
```

```
%as tone. The spectrogram of the tone is displayed on the graph and
%ud.sound is played.
ud=get(gcf,'UserData');
if ud.f == 100
    ud.z=zeros(1,length(ud.tones(1,:)));
    specgram(ud.z,[],ud.fs);
    helpdlg('Select a Frequency!','Help');
else
    db=get(handles.level,'Value');
    tone=ud.tones(ud.f,:)*10^(db/20);
    ud.z=zeros(1,length(ud.tones(ud.f,:)));
    ear=get(handles.rightear,'Value');
    if  ear == 1
        % invert sound matrix to switch to right ear
        ud.sound=[ud.z;tone];
    else
        % invert sound matrix to switch to left ear
        ud.sound=[tone;ud.z];
    end

    axes(handles.graph);
    specgram((tone/2/pi),[],(ud.fs/2/pi));
    wavplay(ud.sound',ud.fs);
end


% --- Executes on button press in mspeech.
function mspeech_Callback(hObject, eventdata, handles)
ud=get(gcf,'UserData');
%ud.male gets multiplied with the amplitude from the level (Slider), and is
%stored in male. According to the selected radio button, right or left, one
%of the column is set to zero. The spectrogram of the male is displayed on
%the graph and male is played.
fs=44100;
db=get(handles.level,'Value');
```

```
male=ud.male*10^(db/20);
ear=get(handles.rightear,'Value');
if  ear == 1
    % invert sound matrix to switch to right ear
    male(:,1)=0;
    axes(handles.graph);
    specgram((male(:,2))',[],fs);
else
    % invert sound matrix to switch to left ear
    male(:,2)=0;
    axes(handles.graph);
    specgram((male(:,1))',[],fs);
end

wavplay(male,fs);



% --- Executes on button press in fspeech.
function fspeech_Callback(hObject, eventdata, handles)
ud=get(gcf,'UserData');
%ud.female gets multiplied with the amplitude from the level (Slider), and
%is stored in female. According to the selected radio button, right or
%left, one of the column is set to zero. The spectrogram of the female is
%displayed on the graph and female is played.
fs=44100;
db=get(handles.level,'Value');
female=ud.female*10^(db/20);
ear=get(handles.rightear,'Value');
if  ear == 1
    % invert sound matrix to switch to right ear
    female(:,1)=0;
    axes(handles.graph);
    specgram((female(:,2))',[],fs);
else
    % invert sound matrix to switch to left ear
```

```
    female(:,2)=0;
    axes(handles.graph);
    specgram((female(:,1))',[],fs);
end

wavplay(female,fs);



% --- Executes on button press in append.
function append_Callback(hObject, eventdata, handles)
%Append will collect the current data from Frequency Popup Menu, Hearing
%Level Silder and Selected Ear. freq gets the frequency, db get the hearing
%level, ear get the selected ear, new is the combined string of the three
%variables. Then new is displayed on the List Box.
ud=get(gcf,'UserData');
if ud.f == 100
    helpdlg('Invalid Request!','Help');
else
    freq=get(handles.frequency,'String');
    freq=freq(ud.f+1);
    db=num2str(get(handles.level,'Value'));
    ear=get(handles.rightear,'Value');
    if  ear == 1
        ear='Right Ear';
    else
        ear='Left Ear';
    end
    new=char(strcat(freq,' Hz,',db,' dB,',ear));
    list=get(handles.list,'String');
    list{length(list)+1}=new;
    set(handles.list,'String',list);
end



% --- Executes on button press in remove.
```

```
function remove_Callback(hObject, eventdata, handles)
%This function removes the selected value from the List Box
del=get(handles.list,'Value');
list=get(handles.list,'String');
if length(list) < 1
    helpdlg('Invalid Request!','Help');
else
    list(del)=''
end
set(handles.list,'String',list)
refresh;

% --- Executes on button press in audiogram.
function audiogram_Callback(hObject, eventdata, handles)
%values get the values from the List Box. Then list made into a Numeric
%Matrix. values is split into right and left. freqs is a list of all the
%frequencies. r & l stores the mean of the hearing level of the same
%frequency, which is copied to right and left respectively. right & left is
%split into rf & rdb and lf & ldb, where rf & lf store the frequencies and
%rdb & ldb store the hearing levels. A graph is plot between rf &rdb and lf
%& ldb.
ud=get(gcf,'UserData');
list=get(handles.list,'String');
if length(list) < 1
    helpdlg('Invalid Request!','Help');
else
    values=get(handles.list,'String');
    for f=1:length(values)
        values(f)=strrep(values(f),'Hz,','');
        values(f)=strrep(values(f),'dB,','');
        values(f)=strrep(values(f),'Right Ear','1');
        values(f)=strrep(values(f),'Left Ear','0');
    end
    values=char(values);
    values=str2num(values);
```

```
values=sortrows(values);
indL=1;
indR=1;
for f=1:length(values)
    if values(f,3)==1
        right(indR,1)=values(f,1);
        right(indR,2)=values(f,2);
        indR=indR+1;
    else
        left(indL,1)=values(f,1);
        left(indL,2)=values(f,2);
        indL=indL+1;
    end
end
indL=1;
indR=1;
freqs=[125 250 500 750 1000 1500 2000 3000 4000 6000 8000]';
for f=1:length(freqs)
    indexr=find(right(:,1)==freqs(f));
    if length(indexr)>1
        r(indR,:)=[freqs(f),mean(right(indexr,2))];
        indR=indR+1;
    end
    indexl=find(left(:,1)==freqs(f));
    if length(indexl)>1
        l(indL,:)=[freqs(f),mean(left(indexl,2))];
        indL=indL+1;
    end
end
right=r;
left=l;
for f=1:length(right)
    rf(f,1)=right(f,1);
    rdb(f,1)=right(f,2);
end
```

```
    for f=1:length(left)
        lf(f,1)=left(f,1);
        ldb(f,1)=left(f,2);
    end
    axes(handles.graph);
    plot(rf,rdb,'ro-.',lf,ldb,'bx-.');
    grid on;
    xlabel('Frequency Hz');
    ylabel('Hearing Level dB');
    title('Audiogram');
end
```