NTNU
Det skapende universitet

Personlig tilpasning av HRTF-sett for 3D-lyd

Kristian Brox

Master i elektronikk
Innlevert: juli 2016
Hovedveileder: Odd Kr. Pettersen, IET

Norges teknisk-naturvitenskapelige universitet
Institutt for elektronikk og telekommunikasjon

Problem Description

To achieve good 3D sound using headphones, it is important to use the right Head-Related Transfer Functions (HRTFs), preferably the set belonging to the listener. This can be found either with extensive acoustic measurements or 3D scanning of the head and torso.

SINTEF wishes to examine alternative methods for adapting the HRTFs. One possibility is that the listener itself finds its way into the best set by listening to 3D sound with a head-tracker. This can i.e. be done with an iterative process where HRTF parameters (head shape, location and design of pinna, ...) can be adjusted by selecting what sounds most realistic. Here one can either rely on a theoretical HRTF model, or a set with measured HRTFs with known anthropometric measurements. The task includes studying relevant literature, specification of an adaptation method and evaluation of the method.

Preface

This thesis marks my final work as a student at Norwegian University of Science and Technology (NTNU). During the last 5 years a lot of knowledge, new connections, and many friends has been made, and this I appreciate greatly. The thesis was carried out during the spring semester of 2016, from January to July, and it was written for the research company SINTEF.

Binaural hearing is something that has interested me for a long time, and it peaked my interest when it was introduced in the third year of the Electronics study program. When SINTEF announced the problem on binaural hearing, it was immediately considered the most exiting choice for me. This gave me the opportunity to work as a researcher on something I was passionate about, and a chance to develop something new from scratch, which has made the work much more fun and easier.

I would like to thank SINTEF, and my supervisor Prof. Odd Kr. Pettersen, for this great opportunity. A big thanks goes to my other supervisor, Audun Solvang, for many great advises and inputs, and for helping me structure my work process. I also would like to thank all the subjects participating in my experiment, for which you will always be appreciated. In addition, I want to mention Jakob Vennerød, my supervisor for the project thesis, as he helped me develop the fundamentals for this work.

A huge thanks goes to all my fellow students for making a great study environment, and for sticking together, day and night, at our shared reading room.

Trondheim, July 15, 2016

Kristian Brox

Abstract

To benefit from our highly sophisticated spatial hearing in virtual applications, a Head-Related Transfer Function (HRTF) set is necessary in order to realize it using headphones. Unfortunately, this transfer function varies between people due to our anthropometric differences. Using a HRTF set belonging to someone else can result in inaccurate perception of sound directions and confusion. Typically this function is measured in an anechoic chamber using a tedious process.

In this thesis, alternative methods to obtain a personal HRTF set for the horizontal plane has been reviewed. An approach reusing existing HRTFs from the CIPIC HRTF database, which is measured on people using the tedious processes, was investigated further. This resulted in the development of an algorithm that tests and combines various HRTF sets into a new, and personalized set, based on how well a user performs at localization tasks in different situations. This approach is unique, as nothing similar has been done before.

The algorithm was implemented using MATLAB Graphical User Interface (GUI). 20 participants used the implementation to obtain their personalized HRTF sets. In an experiment, the performance of these sets were tested against an average HRTF set, and the HRTF set corresponding to the head closest to the participants' head diameters.

The results show that there are no statistical significant differences between the HRTF sets tested. The personalized- and closest diameter HRTF sets seemed to perform slightly more accurate than the average when it comes to accuracy and front-back confusions, although this might be the result of coincidences. Considering the results, the proposed methodology for obtaining personalized HRTF sets is not recommended to investigate further.

Sammendrag

For at vi skal kunne benytte oss av vår binaurale hørsel i virtuelle applikasjoner, ved bruk av hodetelefoner, trenger vi Hode-Relaterte Overføringsfunksjoner, forkortet til HRTF på engelsk. Uheldigvis vil denne HRTF'en være forskjellig fra person til person grunnet våre antropometriske ulikheter. Ved å benytte seg av andres HRTF'er kan lydkilders posisjon oppleves unøyaktig, og kan føre til forvirring. I dag blir som regel HRTF'er målt i ekkofrie rom ved bruk av en langtekkelig metode.

I denne oppgaven har alternative måter for å oppnå et personlig HRTF-sett i horisontalplanet blitt utforsket. En metode som går ut på å gjenbruke tidligere målte HRTF'er fra CIPIC-databasen ble undersøkt videre. Dette resulterte i utviklingen av en algoritme som tester samt kombinerer ulike HRTF-sett til et nytt og personifisert sett, basert på hvor godt brukere utfører lokaliseringsoppgaver i ulike situasjoner. Dette er en unik metode ettersom noe lignende ikke er blitt gjort før.

Algoritmen ble implementert ved hjelp av MATLAB GUI (engelsk forkortelse for Grafisk Brukergrensesnitt). 20 personer brukte implementasjonen for å oppnå deres personlige HRTF-sett. Yteslsen til det personlige settet ble sammenlignet opp mot et gjennomsnittlig HRTF-sett, samt et HRTF-sett fra databasen som tilhørte den personen med mest mulig lik hodediameter som testpersonen.

Resultatene viste at det ikke var noen statistisk signifikant forskjell mellom HRTF-settene som ble testet. Det virket som det personifiserte- og det nærmeste diameter-settet førte til litt mer korrekte lokaliseringsresultater samt færre tilfeller front-bak-forvirring enn gjennomsnitt-settet, men dette kan ha vært forutsaket av tilfeldigheter. Tatt resultatene i betraktning er den foreslåtte metoden for å oppnå et personifisert HRTF-sett ikke anbefalt å utforske videre.

Table of Contents

List of Tables

List of Figures

Abbreviations

ANOVA	Analysis of Variance. xi, 23, 24, 27, 31
GUI	Graphical User Interface. v, xiii, 11, 13, 15, 22
HRIR	Head-Related Impulse Response. 3
HRTF	Head-Related Transfer Function. v, xiii, 2, 3, 5, 7, 8, 9, 10, 11, 15, 16, 21, 22, 23, 24, 25, 26, 27, 28, 31
ILD	Interaural Level Difference. 5, 9, 16, 31
ITD	Interaural Time Difference. 4, 9, 16, 28, 31
NaN	Not a Number. 35
NTNU	Norwegian University of Science and Technology. iii

Chapter 1

Introduction

The human hearing is a detailed and highly developed sensory input, both in a technological and evolutionary perspective. It is one of our sensors that always is active, and it is helping us in daily use even if we don't think much of it. We walk to the side of the road when we hear a bicyclist approaching from behind, we look towards and direct our attention to the person who starts speaking on the other side of the dining table, we can listen to the news on the radio while driving, we get a family member to call our phone when it is unknowingly lost under the coach cushion when we are late for an appointment, and so on. The beauty of our hearing is that we use it in functional or recreational ways, while the rest of our body is completely free.

There is a lot of information in sounds. From the sound alone we can often determine what makes the sound, who is speaking, and understand what the person is saying. One other important property coded in what we hear is where the sound is coming from. This property is essential in three of the four cases from daily life mentioned above: Without directional hearing the bicyclist might have hit us, we would have to look at each and everyone's mouths in order to know who was speaking, and we would have had a hard time locating that phone.

Our ability to locate sounds is caused by our binaural hearing. If localization wasn't important we would probably only have one ear. With two ears we can determine the sound source's direction in the horizontal plane with good accuracy, we can hear the source's elevation, and we can with some accuracy determine the sound source's distance. We can even locate several sound sources at the same time, and two ears also makes them easier to distinguish from one another.

The full use of binaural hearing is essential and integrated in our daily lives. Unfortunately, this is not so much the case in virtual applications. Almost all music recordings we listen to is made for stereo speakers. The speakers gives some directional perception, but is not close to the resolution and space we are capable of perceiving. We even often use headphones, playing the same signal meant for speakers, which often places the perceived sounds inside the head.

It is possible to take full advantage of our binaural hearing using headphones. This can be done using something called Head-Related Transfer Functions (HRTF). The HRTF sets needed is however different for everyone as a result of everyone's unique anthropometry. The typical method of measuring each individual's HRTF set is tedious and expensive. If there was an easy way, there could be unlimited of different applications where we could benefit from virtual binaural hearing.

HRTFs is not something new, and it has been researched by among Jens Blauert, and a famous book, by him, on the topic titled "Spatial Hearing" was released already in 1974 [2]. Since then, various people have researched the field. There have been many attempts to find alternative methods for achieving personal HRTF sets. Some of the methods and research will be discussed throughout this thesis. Building on one method, a new approach will be developed, implemented, and tested to see if it can substitute todays tedious method of measuring a HRTF set.

1.1 Objectives

The main objectives of this Master's project are

1. Study various methods for obtaining a personal HRTF
2. Choose a promising approach and investigate it further
3. Develop a solution to the problem and implement it
4. Test the solution and determine whether it is a good solution

1.2 Outline

Chapter 2 covers the theoretical aspects of our directional hearing and explains terminology and abbreviations.
Chapter 3 reviews various approaches for obtaining a personal HRTF. One approach is investigated further, and an implementation is discussed and revealed.
Chapter 4 discusses how a testing procedure will be done, and then describes the methodology used in an experiment
Chapter 5 reveals an error in the code, reviews the statistical analysis to be used and presents and discusses the results
Chapter 6 concludes the work

Chapter 2

Theoretical Framework

In this chapter the most important theory for this thesis will be presented. It is adapted, reevaluated, modified, and added to from the author's project thesis. This chapter is not meant to be a complete description of the field, but rather serve as the basic knowledge needed to understand the thesis as a whole. There are lots of sources of information that can be viewed, elaborating the field in more depth [3][2][4].

Head-Related Transfer Function, HRTF

A HRTF, or Head-Related Impulse Response (HRIR) in the time domain, describes how the frequency spectrum of a sound wave is altered before it arrives at the ears. The transfer function will depend on the incident angle, both azimuth and elevation, and the distance from the source. Unless the sound source is placed on the median plane, which is the x_2-x_3 plane in figure 2.2 in the following subsection, the HRTF will differ for the two ears. Having the HRTF for both ears, it can be used for binaural synthesis [5]. This is illustrated in figure 2.1. Any mono sound can be placed virtually anywhere in space, by being filtered through the HRTF for the left and right ears, separately, and then played over headphones.

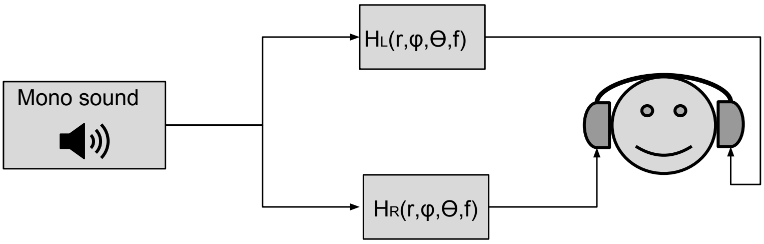


Figure 2.1: Virtualization of 3D-sound

CIPIC database

Throughout this thesis the CIPIC database is used, which is free to use for "any purpose-educational, research and commercial. However, each reproduction ... must include the copyright notice"[6] (Copyright © UC Regents, Davis Campus. All Rights Reserved).

The database includes the HRIRs of 45 different persons in $25 \times 50 \times 200$ arrays. This corresponds to 25 different azimuth measurements, both in front and behind the head, 50 different elevation measurements, and 200 time samples. Figure 2.2 shows the head-centered interaural-polar coordinate system CIPIC is using. Here θ corresponds to the azimuth angle, while ϕ is the elevation angle. CIPIC has defined the azimuth angle to be the angle between the source and the median plane. However, when the azimuth plane is mentioned elsewhere in this thesis, it will be defined as the horizontal plane corresponding to the x_1-x_2 plane in figure 2.2, and not the angle θ from the median plane.

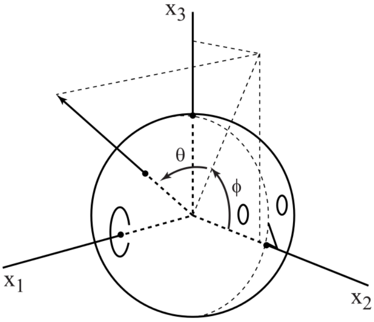


Figure 2.2: CIPIC coordinate system [1]

Directional hearing

To locate a sound we use four cues: arrival time difference between the two ears, sound level difference between the two ears, spectral cues, and dynamic cues. These will be elaborated separately in later theory sections. Our directional hearing is many times better using both ears compared to monaural listening. The accuracy of locating a sound is both dependent on its frequency spectrum, and where the source is placed relative to the head position. The human ability to locate sounds also increase the more information the sound contains, as we can use the different cues at the same time. With more directional cues, the robustness of each cue gets evaluated to better locate the source [4]. We determine the position of sound sources with highest accuracy right in front of us in the azimuth. Here, we can distinguish two sound sources down to about 1° on average. The accuracy decreases the more off center the sound source is. The worst accuracy is directly at our sides, while it gets better the closer the source is directly behind us. [3][4]

Interaural Time Difference, ITD

Information used to locate a sound related to the difference of arrival time between the two ears is called Interaural Time Difference (ITD) [2]. If a sound arrives at the right ear before the left, the sound is perceived to come from the right side. This is a result of the longer travel distance a sound will have to arrive at the left ear compared to the right, when the sound source is placed at the right side. For frequencies below approximately 1.4 kHz, ITD is the primary cue used to determine the sound source's position. For frequencies above 1.4 kHz, the ITD gradually ceases to be the primary cue as the frequencies increases. [3]

Interaural Level Difference, ILD

Dissimilarities relating to the sound pressure level on the two ears are called Interaural Level Difference (ILD) [2]. There will be a level difference when the sound source isn't placed on the median plane. The sound pressure level will be strongest on the ear closest to the source due to shadowing of the head. The difference is biggest for higher frequencies as they have a shorter wavelength and are attenuated easier. Above 1.5 kHz, both ILD and ITD are used as localization cues, but ILD becomes more and more dominant for higher frequencies. [3]

Spectral cues

To determine the elevation of a sound source, especially in the median plane, spectral cues are dominant. It is possible to use spectral cues for sound localization because the frequencies are altered differently depending on the elevation. The pinna, which is the visual part of the outer ear, attenuates and amplifies different frequencies for different incident angles of the sound, particularly for frequencies above 5 kHz. [3]

Front-back confusion

In some situations a front-back confusion can occur. This is when it is hard to tell if a sound source is located in front of, or behind us. It is especially prone to happen when using a HRTF that isn't fitting well [7]. Consider the case in figure 2.3. It shows a head viewed from above. There are also two sound sources, one in front of the head and one behind the head. Both angles, α and β, are the same. Regardless of which speaker is playing, the difference in ILD and ITD will be quite similar. This is because the relative distance and shadowing is almost the same in both cases. Thus, to determine if the sound source is playing in front or behind, spectral cues is used. In this case, the dynamic cue also plays an important role, which is achieved by slight head movements. [3]

Linkwitz-Riley filter

Linkwitz-Riley filters are often used in audio applications. It can be made by cascading two Butterworth filters, which is designed to have as flat frequency response as possible in the passband. The two Butterwoth filters each have a -3 dB gain at the cut-off frequency, while the Linkwitz-Riley filter gets a -6 dB cut-off. When two Linkwitz-Riley filters, one low pass and one high pass with the same cut-off are added together, the gain at the crossover frequency will be 0 dB resulting in an all-pass filter. [8]

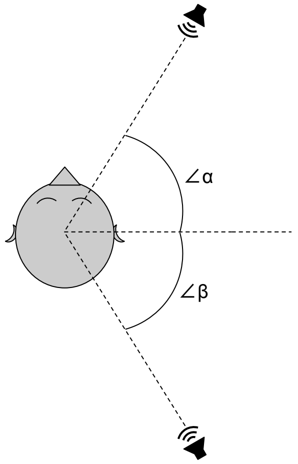


Figure 2.3: Front-Back confusion

Chapter 3

Implementation

This chapter reviews different approaches for obtaining a personal HRTF, and then discusses and reveals the chosen approach to investigate. This is followed by a complete description of an implementation. The section "Possible Approaches" is reevaluated and adopted from the author's associated project thesis, with several modifications and additions, as the information and discussion regarding different approaches still holds.

3.1 Possible Approaches

Impulse Response in Anechoic Chamber

Measuring the HRTF in an anechoic chamber is probably the most common method to obtain a HRTF, and at least what most of the more recent HRTFs made today is based on. An anechoic chamber is a room with absorbing material on the walls, floor and ceiling, designed to work as a free field, meaning there should be no reflections and only a direct sound from any sound sources within the room [9]. To obtain the HRTF of a person, he or she has to wear a microphone in both ears. Then the impulse response is measured at by the microphones by placing a loudspeaker at all the directions the HRTF is needed, while playing all the wanted frequencies inside the chamber.

This method is intuitively the one giving the best result as one is physically measuring how the sound is altered from different angles before arriving at the ears. It is however a tedious task to measure the impulse response from many directions. Also, it requires a carefully crafted setup in an anechoic chamber to get it right. For instance, the distance to the loudspeaker has to be equal in all directions. Considering the time it takes for the person and the time used in the chamber, which usually also is used for various other measurements, obtaining the HRTF naturally becomes quite expensive and most likely not something many will go through.

One possible approach to look into could be finding a way of altering the traditional impulse response method. It may be possible to find the HRTF for all directions by only measuring for very few "main" directions. This approach would at least decrease the time used. Using several loudspeakers, where some loudspeakers played at the same time with different frequencies is also something that would be time-saving.

Another idea considered is scanning the head and part of the torso, followed by 3D-printing it. This would at least minimize the time used for the person requiring a HRTF. The 3D-printed figure could be printed in a smaller scale, say one tenth, and thus scaling the frequencies used in the impulse response to be ten times higher to compensate for the sculpture size. This way it would be possible to use a much smaller anechoic chamber, also not requiring as thick absorption material considered using higher frequencies. It should also be easy to move the printed head, keeping the speaker position fixed, and it would also be easy to keep the head perfectly still during the measurements. However, this requires a good method for scanning and also an accurate 3D printer. The 3D printer in itself is quite expensive, at least if the printing accuracy should be good. Also the printed material should have the same reflecting properties as humans, which could be hard to accomplish.

HRTF Database

Although measuring the HRTF in an anechoic chamber is expensive and time consuming, there are still carried out measurements for at least some hundred individuals. These are mainly measured for scientific research. Some databases containing HRTFs are free to use for anyone and can be downloaded from various web pages. [10]

With so many different HRTF sets, most people may be able to find a suitable, or even several suiting sets. One recent study concluded there wasn't a significant error differences between persons' own HRTFs and a HRTFs selected from a database. This was the case in azimuth, when the participants were using head tracking [11]. Another study tried different tournament procedures where persons, over several stages, subjectively chose the better of two HRTFs presented. The study found that "appropriate HRTFs can be chosen by subjective evaluation with high probability" [7].

It can seem like, by using existing HRTF databases, it is possible to find a suiting HRTF set. It can also be a cheap and fast way to achieve it. Furthermore, the required equipment would be kept to a minimum.

Anthropometric Measurements

One possible approach could be doing anthropometric measurements. It could for instance be mixed with a database approach; by measuring things like the head diameter and maybe some pinna characteristics it could be much faster to choose the best HRTF. However, one drawback is that there are not always much anthropometric information of the subjects in HRTF databases. Also a standard procedure for doing anthropometric measurements related to binaural hearing is yet to be set [3].

It could also be possible using measurements of, for instance head, torso and pinna to calculate the HRTFs analytically. A 3D scan could also be done. Making a good model for this could however be tricky, and it's hard to predict how well it would work.

3.2 Chosen Approach

When choosing an approach to investigate further and test, some important aspects considered were that it should be accessible, cheap and easy for the users, adaptable, and promising. With this in mind the HRTF database-approach was considered the most fulfilling subject. As there are plenty of HRTF databases accessible to use freely for any purposes, with some such as CIPIC also containing anthropometric measurements, allot of possibilities are open. Also, as mentioned, previous research has proven to be promising on the aspect of using HRTF sets belonging to other persons.

When digging into the chosen approach an idea appeared: To tailor one HRTF set for a person using multiple existing sets from a database. This is something that hasn't been done before, at least not found do have taken place, and gives the possibility to create a new and personalized HRTF set.

The database chosen to use for the implementation was CIPIC. As mentioned, in addition to having a relatively large database of 45 individual HRTF sets with high resolution measurements, it contains anthropometric measurements from the persons with 37 of the sets.

One way chosen to divide the sets was splitting them into various directions. The idea is to find the most suiting HRTF set for each orientation. Figure 3.1 visualizes how the head was split into 10 individual zones. Each zone contains 5 measured directions from the CIPIC database. Each CIPIC HRTF set has 50 measurements in azimuth, with a higher concentration right in front and right behind the head. This results in narrower zones in front and behind as well, and is a wanted result due to our directional accuracy when it comes to locating sounds.

Another way chosen to divide the sets was to split them into two frequency parts, and find the most suiting set for each frequency range for each zone. One approach could be to choose the frequency limit to correspond to the somewhat vague limit between ITD and ILD. Both ITD and ILD are however considered to relate directly to the head size, and it was believed that they may have resulted in using the same set for both frequencies. The frequency content of the HRTFs was instead split into a head size- and a pinna part, as the pinnae is individual for each person, but only affecting the HRTF for higher frequencies. The frequency limit dividing the two was sat to be at 5 kHz. Instead of filtering each HRTF set, the sound stimuli, which was white noise, was filtered. A Linwitz-Riley filter was used to get a flat frequency response when recombining the sets.

To determine whether or not a HRTF set is suiting the user well, a sound stimulus is presented to the user in a zone direction unknown to the user. The user then expresses where the perceived direction of the sound, and the angle deviation determines how great the fit is. One could test each of the HRTF sets in the CIPIC database, for each zone and frequency, but that would have been extremely time consuming. Instead, the set to test out is based on how the user perceived the previous set. If the user perceived a sound source as being to the right of the direction of the presented sound, as illustrated in figure 3.2, the sound arrives earlier on the right ear than the user is used in real life, and thus a HRTF set from a person with a larger head would result in a more accurate perception. A HRTF set from a smaller head would be more suiting if the perceived sound direction was on the left side of the source in the same figure, as the sound arrived later at the right ear. This approach is used for the adaption for both the head size and pinnae stimuli, as

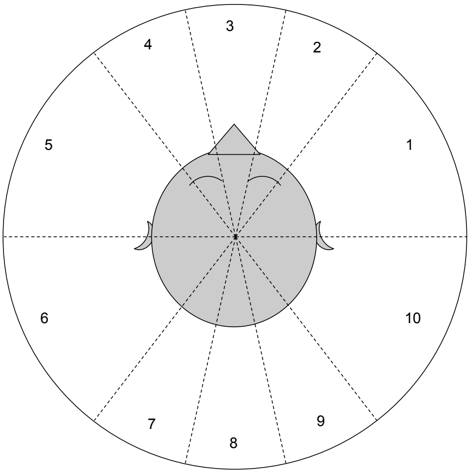


Figure 3.1: Directions split into head zones

no correlation between pinna shape or spectrum and sound direction in azimuth has been found [3]. Also, binaural cues have been found to be favored over monaural cues, even for high frequency stimuli [12].

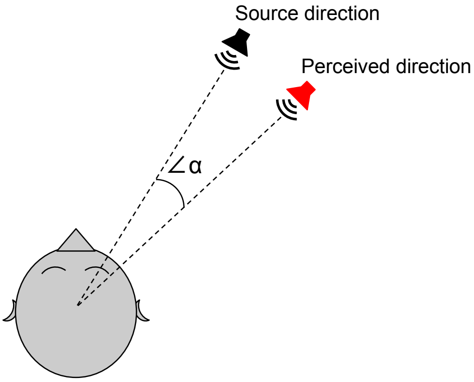


Figure 3.2: Sound source perceived to the left

In order to use the head size approach, all the HRTF sets with anthropometric measurements in the CIPIC database were sorted from smallest to largest, using the diameter measurements. This is illustrated in figure 3.3. The user is first tested for the average head size set, number 19. If a smaller set is believed to be needed, the set right between the average and the smallest, number 10, is tested next.

The numbers below the dotted line in figure 3.3, with arrows pointing upwards above them, shows an example of how the sets are tested. Number 1 represents the first step. The user perceives the sound in such a way that a smaller head is presented in step 2, which is set number 10. For step number 3 a larger head is presented, set number 15. This set is between set 19 in step 1, which was to big, and set number 10 in step 2, which was too small. In step 4 a smaller head, set number 13, is tested, which is the one between the previous big and small tested sets. Again, a smaller head is needed, and set number 12 is tested in the 5th step.

If one HRTF set is found to result in a small enough angle deviation, under 50 degrees, which were sat after testing the approach, it is tested two more times before the next set is tried. Whether the next set should be from a smaller or bigger head is determined from the average angle deviation. The HRTF set with the smallest average angle deviation, that is also tested 3 times, is chosen as the set to use in the personalized HRTF set for the given zone and frequency range. If there aren't any sets under the angle deviation limit, the average set is tested again followed by the same procedure.

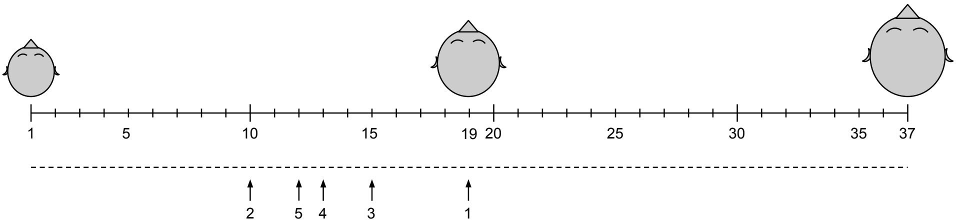


Figure 3.3: Head size approach

Figure 3.4 shows the flow chart of the final algorithm. The personalized HRTF set is first adapted for each zone for the head size frequency range before the pinnae personalization starts. The zones are not finished successive, but randomly picked until a suiting set is found in each of them. The sound stimuli is also played from one of the 5 angles, in an arbitrary direction, within each zone. The user is blind, and receives no information on the direction of the stimuli or how well it is performing.

The algorithm was implemented using MATLAB GUI. A screen capture of the implementation can be seen in figure 3.5. It shows a birds eye view of a head, a text box with information, a start button and a crosshair. At the beginning of the algorithm, the user can click on the start button when ready. The first sound stimulus is then played in a random direction. The user can then move the crosshair, and click in the perceived direction. The distance from the head does not affect the result, only the angle. If the user wants to listen to the sound once more, the user can click inside of the head. This was a wanted feature from test users, before the final implementation was made. The users have no time limit to express their perceived direction of sound, and the text stimulus is played half a second after each click of the crosshair. When the personalization is finished, a message revealing this appears in the text box.

In the MATLAB implementation, the angles 0° and 180°, corresponding to right in front and right behind the head, were not used as sound stimuli. This was a result of the head size approach. The approach is based on the idea that either a bigger or a smaller head should be tried next for the given zone. This approach is however pointless for incidence angles coming from straight ahead or right behind a person, as the sound will arrive more or less at the same time and be equal in strength on both ears due to having the same travel

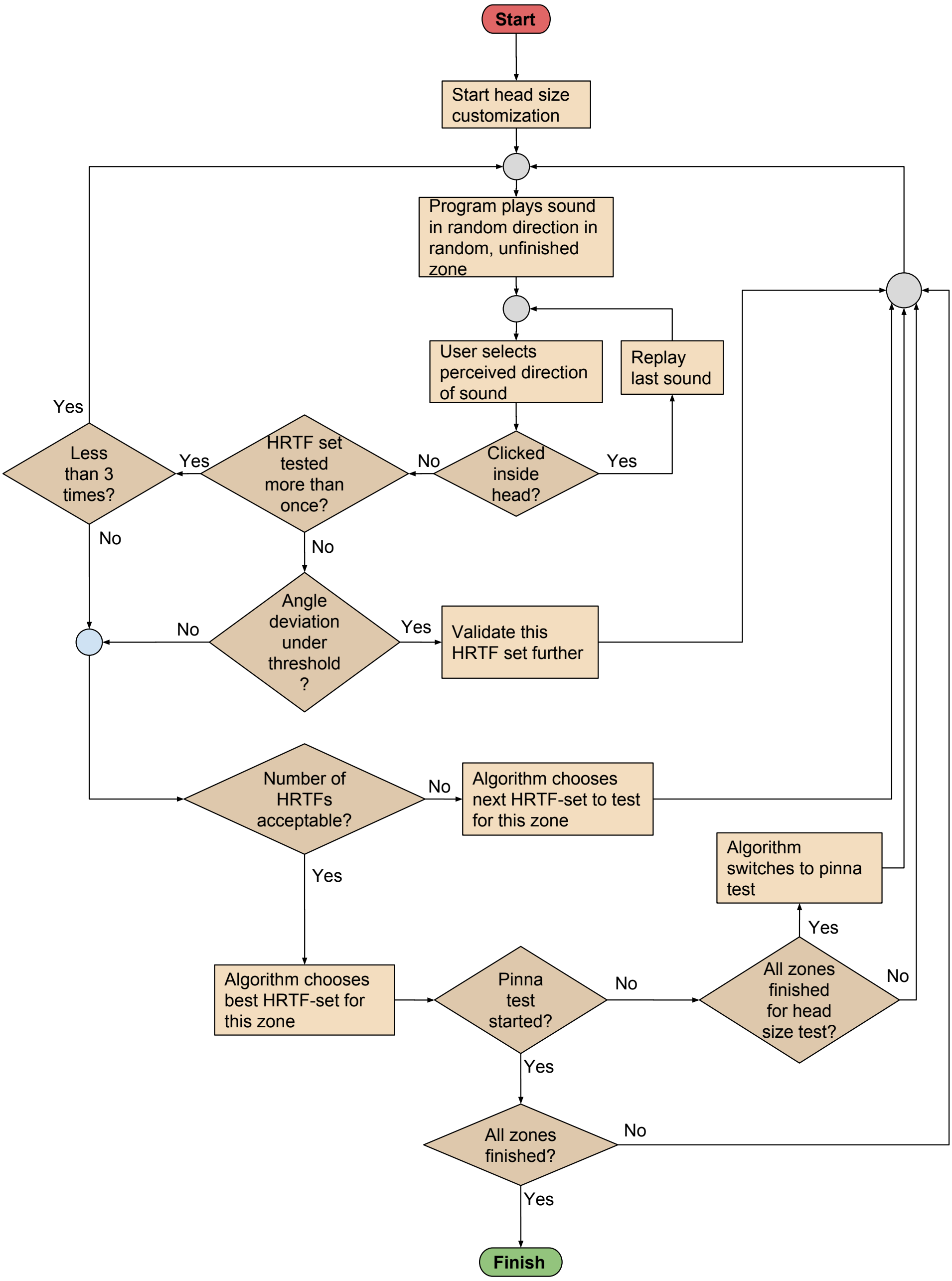
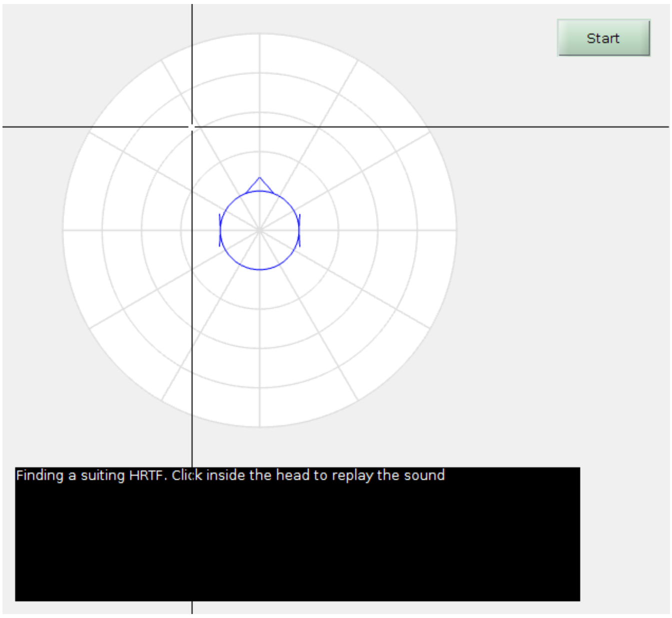


Figure 3.4: Flow chart of algorithm

distance. From this, it is not possible to propose a bigger or smaller head based on the perception. The angles 0 and 180° should thus not have the chance to determine the final

HRTF-set chosen for the respective zones. The angles 5° from 0° and 180° were however used in the personalization.



Finding a suiting HRTF. Click inside the head to replay the sound

Figure 3.5: MATLAB GUI implementation

Chapter 4

Experiment

In this chapter the parameters to be tested, and an approach to compare the personalized HRTF set is described. This is followed by a complete review of the methodology used in an experiment.

4.1 Test Algorithm

In order to tell how well the HRTF sets given by the implemented algorithm works, it should be tested. If it turns out a person performs equally, or even worse, when using the personalized HRTF-set compared to another, non-personal, HRTF-set, there is no point in using the implementation. This is also the case if using the algorithm only causes slightly better results. In the latter case, the time and effort invested in finding the most suiting HRTFs might not be worth the slight improvement. If, on the other hand, localization is considerable more accurate using the personalized HRTF set, it indicates that the algorithm might be useful for a plethora of different applications.

Before designing a test some hypotheses were made

1. The personalized HRTF set works better than an average set
2. The personalized HRTF set works better than using a set from a simple head measurement
3. Personalizing the HRTF set for two frequency ranges corresponding to head size and pinnae is sufficient

To test the personalized HRTF set, the GUI from the implementation was used. Again, the angle deviations from the presented sounds work as the indication of how well a set suits the user. The personalized set given from the implementation is compared against two other HRTF sets; one average set, and one set closest to a head diameter measurement of the user. The average set used is the median set from the CIPIC database, when sorting the sets after diameter, corresponding to number 19 in the head size approach for the personalization algorithm. This is used to see if most people rather could use the same set, instead of using the personalized from the implementation. The HRTF set closest to a diameter measurement of the user was chosen for the comparison to see if a simple anthropometric measurement could result in the same, or a more accurate performance.

The sets are also tested for three frequency ranges. The ranges are

1. Low frequency, corresponding to ITD
2. Middle range, below pinnae frequency, corresponding to ILD
3. Full frequency range

The ITD and ILD ranges are tested to see whether the head size and pinnae personalization works, or if the head size frequency range in the personalization implementation rather should have been split into ITD and ILD as well. The full frequency range is tested to see how well the personalized HRTF set performs as a combined set.

To keep the test procedure at an accepting time duration, the sets, for each frequency range, is tested once for each of the 10 zones. The angle in the middle of each zone is tested, to get equal testing conditions. Here, the angles right in front and behind the head, which was removed for the personalization implementation, are included.

Prior to the experiment, a random Latin square matrix was computed to reduce blocking factors in the experiment [13]. A Latin square matrix is a N-by-N matrix, where each row and each column contains all of the integers from 1 to N. Each of the integers will only appear once in each column and in each row [14]. A simple example of this can bee seen in table 4.1. In a random Latin square matrix, the content of each row and column also have a random uniform distribution. This has been computed by first making a normalized Latin square, which means the first row and column are in their natural order from 1 to N, then randomizing the order of the columns and rows, using random permutation. The matrix was made in order to randomize the testing procedure, in addition to make the test order unique for each participant. Three HRTFs were to be compared: the personalized, an average, and the closest diameter set. These should be compared by testing the deviation from a played angle with three different frequency bands, in each of the 10 head zones. This gives $3(HRTFs) \times 10(zones) \times 3(frequency\ bands) = 90 cases$, and thus a 90 × 90 random Latin square matrix was made. Each participant was handed out an unique, 90 sequence long, row from the matrix when testing.

Table 4.1: Simple Latin square

1	3	2	4
4	2	1	3
2	4	3	1
3	1	4	2

In order to use the matrix, the meaning of each number from 1 to 90 was defined. This has to some degree been arbitrary chosen, but it was chosen to be tidy and easy to remember for later use. The numbers 1 to 30 are defined as representing the personalized HRTF, 31 to 60 represent the average HRTF set, and 61 to 90 to the closest diameter HRTF set. Each of these HRTF blocks of 30 integers was again split into three blocks of 10 integers. These blocks corresponds to the frequency splitting of ITD, ILD, and ITD+ILD. The numbers in the 10 sized blocks represents each of the 10 head zones respectively.

4.2 Experiment Procedure

The experiment was performed at NTNU in the Acoustic hall in room D0008. The room consists of two smaller rooms separated by a wall containing a glass window and two doors facing each other for airlock. The room and experiment setup is illustrated in figure 4.1.

Each test participant completed the following steps in their respective order:

1. Sign consent form
2. Perform audiometry test
3. Measure head circumference
4. Measure head width
5. Complete personalization algorithm
6. Complete test algorithm
7. Give feedback

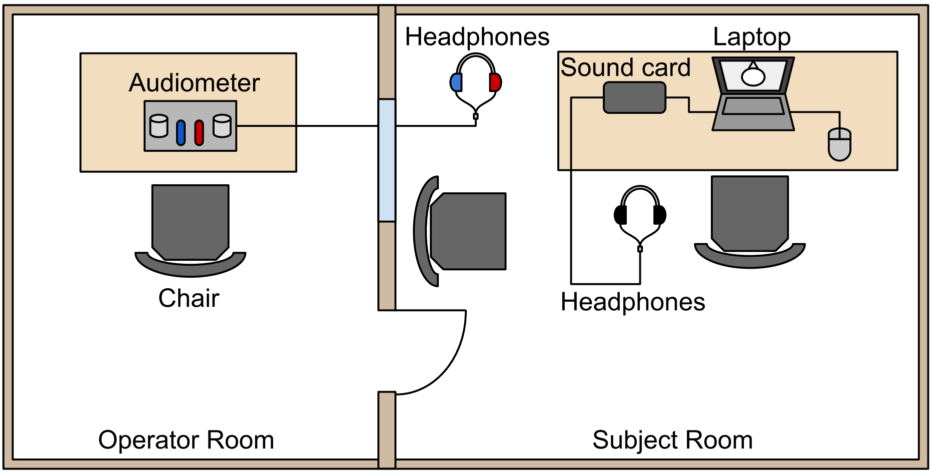


Figure 4.1: Experiment room setup

A consent form had to be read and signed by every participant as hearing is sensitive personal information. The consent form used can be found in figure 6.1 and 6.2 in Appendix. If the participant agreed with the form, an audiometry test was performed. This was done by using an audiometer with headphones. The audiometer was placed in the "Operator Room", on the left side in figure 4.1, while the accompanying headphones were in the "Subject Room", with the wire pulled through a hole in the wall. The hole was sealed with mineral wool to minimize the sound transmission between the adjacent rooms. A ventilation system leading to the subject room was turned off for each hearing testing to keep a more quiet environment for the listener. The listener sat in the middle chair in 4.1, in front of the window, facing the opposite direction of the "Operator Room". The test leader operated the audiometer in the leftmost chair. As some of the audiometer equipment was missing, the participant had to raise a hand whenever a sound was heard. This could be observed by the operator through the window.

All the participants were tested using sine wave stimuli for the octave band center frequencies from 250 Hz to 8 kHz. The audiometry procedure was performed as described in [15]. The minimum audible sound level was found on the right ear for all frequencies before the procedure was repeated for the left ear. First a pure tone of 1 kHz was presented at 15 dB HL (Hearing Level). If the participant perceived the stimuli, the intensity was decreased by 10 dB. If it was not perceived, the stimuli was increased by 5 dB. The decreasing and increasing of intensity was repeated until the lowest audible intensity for 1 kHz pure tone was found. The same procedure was then carried out for the other frequencies. 0 dB was the lowest intensity setting for the audiometer used.

To measure the two head dimensions a ruler, thin rope and a folding rule were used. The head circumference was measured using the rope. It was firmly lead around the participant's head, just above the eyebrows and ears. The two ends meeting was then stretched out straight, and the length was measured using the folding rule.

The head width was found using the folding rule in a partly folded state, as illustrated in figure 4.2. This state of the folding rule was used as a caliper, holding its positions well due to high friction in the joints. The tips were moved to both be in contact with the head, right above the pinnae. Then the caliper was carefully removed and placed on a desk, where the distance between the tips were measured using the ruler, illustrated as the blue transparent rectangle in figure 4.2.

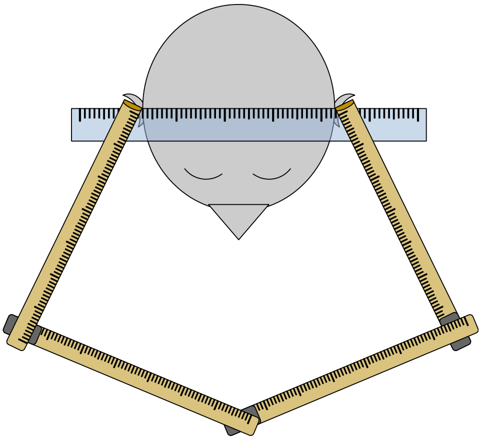


Figure 4.2: Measuring head width

After the two measurements were performed, the algorithm on the laptop illustrated in room setup figure 4.1 was started. Here the test leader wrote the two dimensions into the program. How the GUI worked was explained to the test subject, and then the personalization begun after the test leader left the “Subject Room” and closed the two doors. The personalization was automatically followed by the test algorithm. The audio was played over headphones connected to an external sound card. A PC mouse was used to control the crosshair on the screen.

After the experiment ended, the test subject was asked to give feedback on the overall experience of the experiment.

A detailed list of the equipment used can be found in table 6.1 in Appendix.

Chapter 5

Results

In this chapter the results are presented and discussed. Before this, the finding of an error in the code is brought to light, and the data affected and the possible consequences are discussed. This is followed by feedback from the test participants. Also, the statistical analysis used is defined and reviewed. The results from the audiometry test is not included or discussed. Most participants had normal hearing ($< 25\ dBH$), and no deviations for those who didn't were found. As a result of this, and considering it being person sensitive information, the audiometry data is deleted and not included in the appendix or attachment.

5.1 Error in the Implementation

After the experiment was completed, and the analysis of the results had begun, an error in the implementation code was found:

```matlab
elseif randZone == 1||2||3||8||9||10
```

Here || is a logical "OR" operator. When using logical operators, MATLAB will review all numbers that are not zero, corresponding to a logical false, as a logical true. The code section will always return true, and thus enter the "elseif" statement regardless of which value the variable *randZone* is. The intended line of code should rather have been something like the following:

```matlab
elseif randZone == 1||randZone == 2||randZone == 3||...
        randZone == 8||randZone == 9||randZone == 10
```

The statement in the latter code section is only true when *randZone* is equal to one of the six different numbers listed.

The mistake is located in the personalization algorithm, at the place where the next HRTF to be tested is chosen. As described earlier, based on where the user perceived the sound source, a larger or smaller head is proposed next. The head size picked is dependent on the sign of the angle deviation, and which zone the source was played from. The error in the code results in proposing the wrong head size, a bigger when it should have been smaller and vice versa, for the zone numbers 4, 5, 6 and 7. The error does not affect the remaining 6 zones. Figure 5.1 below shows a visualization of which zones are affected with a red color.

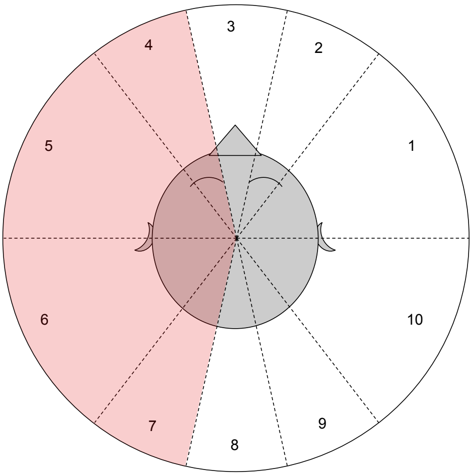


Figure 5.1: Head zones with untrusted ones marked red

Knowing the existence of the error makes it possible to take it into consideration when analyzing the data. Fortunately there is a correct right hand zone, with a corresponding right hand angle, for each untrusted zone. The fault can also make it possible to tell whether the head size approach is a good strategy.

5.2 User feedback

There was a total of 20 different test subjects participating in the experiment. It lasted from 45 to around 70 minutes for each person, depending mostly on how rapidly they reviewed each stimuli.

The test subjects' overall experience of the experiment was that it felt difficult and tiresome, although the GUI was found intuitive. As the algorithm gave no information on whether the perceived sound direction was close to the source or not, it was impossible for the users to tell if they had any progress. A direct feedback for the users to see on the screen, such as the angle deviation for each sound, could unfortunately give a biased personalized HRTF-set as the users could learn where the sound direction came from, even if it wasn't a suiting HRTF for them. In a later implementation there could however be something like a progress bar that tells how much of the adaptation was left.

Another aspect was the test sound used, which wasn't very popular. The noise bursts may have added to the tiresome part of the experiment. Many participants admitted they started clicking faster and less accurate towards the end of the experiment.

Most of the experiment participants experienced a good spatial sensation of the presented sounds, as long as they came from the sides. When the sound source was placed in front of the nose, or right behind, it sometimes felt like being inside the head. Some participants also reported difficulties placing the sound source in their field of view, and rather experienced most sources as coming from behind them, as they couldn't see anything in front of them making the sound. This led to many of the participants closing their eyes when listening for the sounds.

5.3 Statistical Analysis Assumptions

The experiment gives data of the perceived angle deviation from a virtual sound source's direction when the participants are using the different HRTF-sets. The goal of the test was to find out whether or not there is a significant difference in accuracy when using the personalized HRTF-set compared to the two other HRTF-sets. In papers conducting similar tests ANOVA (Analysis of Variance) is typically used [16][17]. ANOVA is a statistical test that compares the variance between, and within, defined groups, in this case corresponding to the different HRTF-sets, and whether there is a statistically significant difference between their means. However, the data values coming from this test are typically spread around the direction of the sound, independent of which HRTF is used. The data samples have either positive or negative signs, depending on whether the user clicked on the left or right side of the source, resulting mostly in a zero mean angle deviation. For this reason the absolute value of the data samples was used in the analysis in order to compare the group means. A more suiting HRTF set, which results in more accurate perception of presented sounds, will result in a angle deviation mean closer to zero.

ANOVA assumes that the populations are independent, that they have a common variance and are normally distributed [18]. The participants were not aware of what, and when they were tested for the different stimuli, and thus could not give hints to following participants. The variances can be visually inspected when analyzing the experiment data. To analyze the accuracy of the different HRTF sets, and to get data that were more normally distributed the front-back confusions were corrected. This also made variances more similar. The correction limits were strict, transforming all data wrongly assumed to be behind to the front, and vice versa. To determine whether the data in fact were normally distributed a visual inspection using MATLAB's normality plot, *normplot*, and by using an Anderson-Darling test on a arbitrary selection were used [19][20]. ANOVA is also known to be robust to modest violations to the normality assumption [21].

The hypothesis to test when using the ANOVA test are:

$$H_0 : \mu_{Average} = \mu_{Diameter} = \mu_{Personalized}$$

$$H_1 : At\ least\ two\ of\ the\ means\ are\ not\ equal$$

Here μ represents the mean. The null hypothesis, H_0, claims there is no difference between the means of the angle deviations using the average HRTF set, the HRTF set closest to the diameter measurements and the personalized HRTF set.

The test gives a *F-ratio* number which is used to find a *p-value*. MATLAB's one-way ANOVA test, textitanova1, is used to find the *F-ratio*s and *p-value*s when comparing the

HRTFs for different zones. The *p-value* is defined as “the probability, under the assumption of no effect or no difference (the null hypothesis), of obtaining a result equal to or more extreme than what was actually observed.” [22]. This means if a *p-value* close to 1 is found, there is a high probability that the means of the groups in fact are the same. If, on the other hand, a *p-value* close to 0 is given, this tells that it is highly unlikely to obtain the data, given that the null-hypothesis was in fact true, and it is more likely that the null-hypothesis is false and the means are statistical significantly different. A limit of $p < 0.05$ is usually followed to determine whether the null-hypothesis should be rejected. If there is a statistical significant difference, $p < 0.05$, a post hoc test, such as MATLAB’s *multcompare* which is a multiple comparison test, can be applied to tell exactly which groups are different, as ANOVA only tells whether there are any differences between any of the groups at all.

When analyzing the data statistically there are 4 possible outcomes:

1. True Positive - Rejecting the null-hypothesis when there actually is a difference among group means

2. True Negative - Accepting the null-hypothesis when the means in fact are the same

3. False Negative - Accepting the null-hypothesis as true when there actually is a difference among the group means

4. False Positive - Rejecting the null-hypothesis when in reality the hypothesis is true

The goal is to either end up with a true positive or a true negative. When doing multiple different ANOVA analyzes there is a higher probability of getting a false positive result, a so-called *type* I *error*, as there are more instances where $p < 0.05$ can happen merely by chance. One possible approach to reduce this risk is to apply the Bonferroni correction method[22]. It states that for *n* comparisons, the new limit should be $p < 0.05/n$. This lowers the possibility of making a *type* I *error* to being the same as only doing one comparison. Using this new limit will however greatly increase the risk of getting a false negative result, a *type* II *error*. Due to this, the original $p < 0.05$ is being used when analyzing the data, but possible risk is kept in mind.

5.4 Presenting Data and Discussion

Testing Data for Normality

To check whether the distribution of the data were close enough to a normal distribution some samples were reviewed. Figure 5.2 shows a normal probability plot of the data, from one of the samples checked, for zone 2, using full frequency stimuli with the personalized set. The plot indicate that the presented data follows a normal distribution, as the blue crosses corresponding to the data points, follows the shape of the red line. This was also the case when running an Anderson-Darling test. After reviewing more date using the same approach, all the data results is assumed to follow, more or less, a normal distribution which is close enough to get valid results from an ANOVA test.

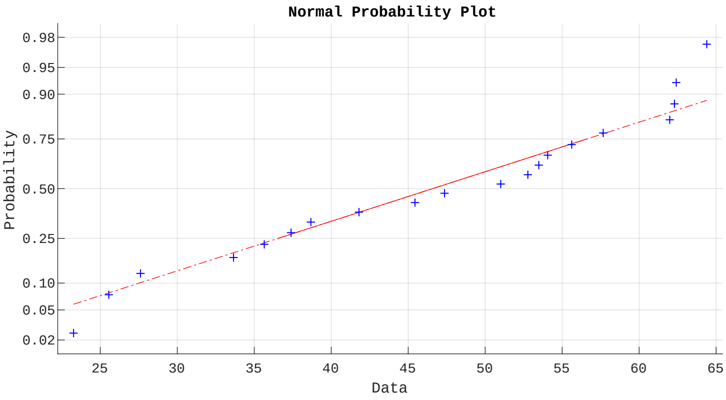


Figure 5.2: Normality plot of full frequency, personalized set for zone 2

Box Plots

All the angle deviation data is presented as box plots in figure 5.3, 5.4 and 5.5, for the high frequency-, mid frequency- and low frequency stimuli respectively. The x-axis represents the 10 different head zones corresponding to 5.1, and the y-axis shows the absolute perceived angle deviation from the sound source in degrees. In each of the three figures the content is split into the results from the personalized HRTF sets, average head sets and the HRTF sets based on the diameter measurements. In each individual box plot the data from each of the 20 participants are included with front-back correction.

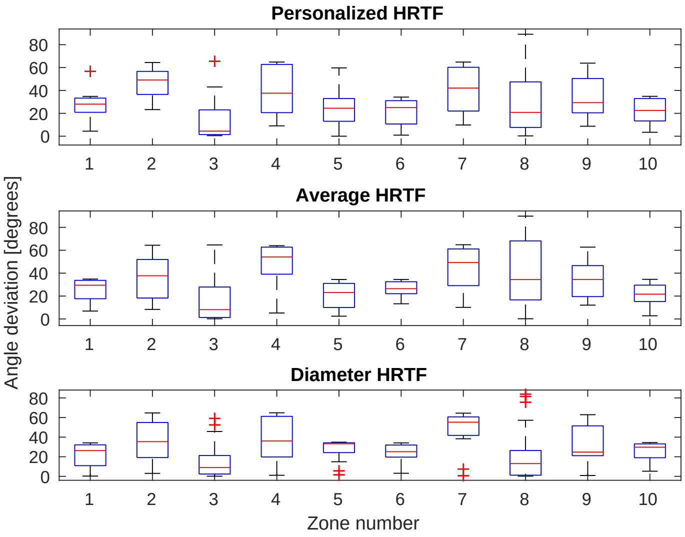


Figure 5.3: Box plots of angle deviations for all zones with full frequency HRTF sets

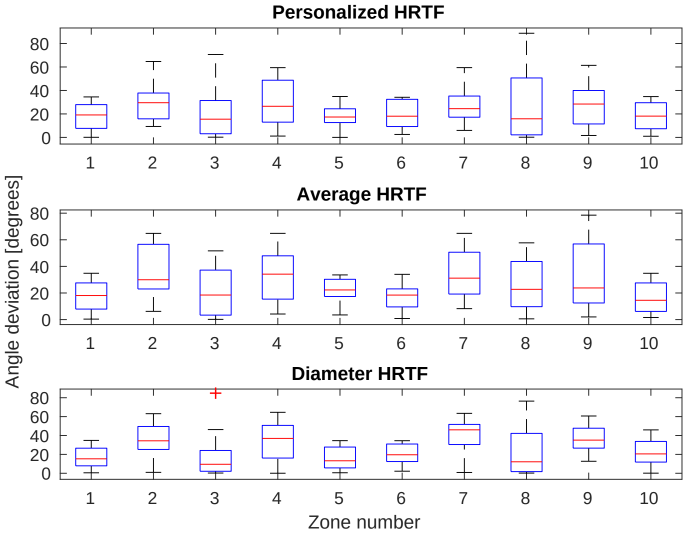


Figure 5.4: Box plots of angle deviations for all zones with mid frequency HRTF sets

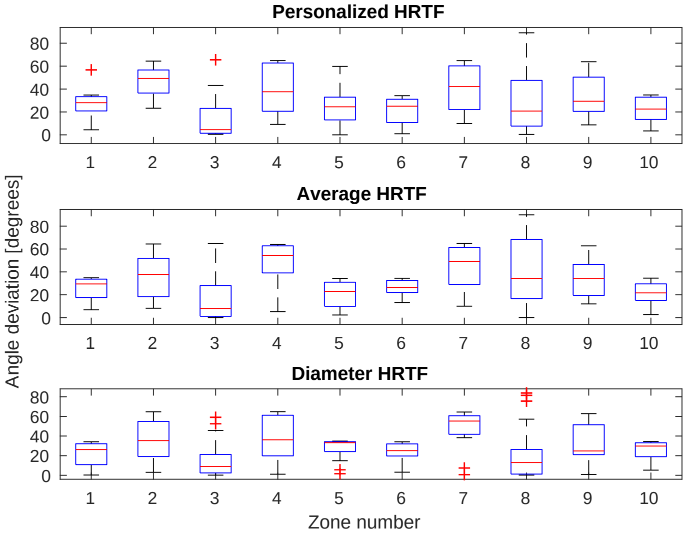


Figure 5.5: Box plots of angle deviations for all zones with low frequency HRTF sets

A quick overview of the plots, looking at the means and whiskers, suggests that there are not large deviations among the different HRTF sets for each head zone. On the other hand, there seems to be some variation among the different zones. It looks like the zones one the sides of the head; 1, 5, 6 and 10, tends to be most accurate overall, despite the fact that that the means for zone 3 and 8, which is right in front and right behind the head, tend to have the lowest means. This is counterintuitive to the fact that we have a higher directional accuracy right in front and behind us. It does however correspond well with the participants' feedback saying the stimuli on the sides were easier to locate. Added to this, the high accuracy might also be a result of the strict correction of front-back confusion, which will be reviewed closer later.

Looking at the box plots for the personalized HRTF sets for the different frequency spectra, it does not seem to be any major difference or consistency between the zones affected by the code error and the corresponding right hand zones. This indicates that the up-down head size approach used when finding a suiting set to test is excessive, or that a better approach might have been chosen.

Comparing all the means between the sets, for each zone, reveals that the personalized and diameter sets tends to be lowest. Only in 4 of the 30 cases the average set has the lowest mean. This might be an arbitrary finding, but it might also suggest that customization will be better than the average set.

Results from ANOVA

In table 5.1 the *F-ratios* and *p-values* obtained from the ANOVA tests are listed. Each *p-value* corresponds to one ANOVA test. The groups used in the test are the three different HRTF sets, and they are compared with the data from the three frequency ranges separately as well as for the individual zones. The zones exposed to the code error are marked red. At the bottom of the table the data from all the zones are combined (All), in addition to combining all the zones that are not affected by the code error (All white).

Table 5.1: F ratio and p-values derived from ANOVA

	Full frequency		**Mid frequency**		**Low frequency**	
Zone	**F ratio**	***p-value***	**F ratio**	***p-value***	**F ratio**	***p-value***
1	0.74	0.48	0.07	0.94	0.48	0.62
2	2.13	0.13	1.57	0.22	0.42	0.66
3	0.09	0.91	0.23	0.8	0.66	0.52
4	1.1	0.34	0.4	0.67	0.04	0.96
5	1.61	0.21	1.64	0.2	0.32	0.73
6	1.45	0.24	0.54	0.59	1.26	0.29
7	1.01	0.37	2.69	0.08	2.84	0.07
8	1.93	0.16	0.13	0.88	0.04	0.97
9	0.1	0.9	0.98	0.38	1.24	0.3
10	0.87	0.42	0.62	0.54	1.92	0.16
All	0.58	0.56	1.25	0.29	1.77	0.17
All white	0.28	0.76	1.53	0.22	1.32	0.27

The table shows that there are no cases where $p < 0.05$, meaning the null-hypothesis can't be rejected with the given limit, and there are no cases where there is a statistical significant difference between the HRTF sets.

The *p-values* ranges all the way from 0.97, down to 0.07. The higher value points towards the tested groups, for the given zone and frequency, having a high probability of having the same means. Whereas the value of 0.07 is almost low enough to reject the null-hypothesis for that test. As mentioned earlier, even if there was found one value $p < 0.05$, it may have been a coincidence as so many ANOVA tests have been performed. The rest of the *p-values* are mostly in the lower middle layer, except for the low frequency range. Comparing the *p-values* for the combined zones, there does not seem to be any deviations between using the zones affected by code error and not, adding to the earlier claim that the head size approach might not have worked that well.

Front-Back Confusions

Figure 5.6 shows how rapidly the general direction of the sound sources were misjudged as coming from the front side when it was placed behind, and vice versa. The 10 head zones are placed on the x-axis, and the number of front-back confusions represents the y-axis. For each zone, the number of confusions is plotted for the personalized, average, and the set based on diameter measurements. The confusions are also split into three parts, three different colored bars, for the different frequency stimuli. The maximum possible number of confusions is 20, which would mean all 20 participants misjudged the source position.

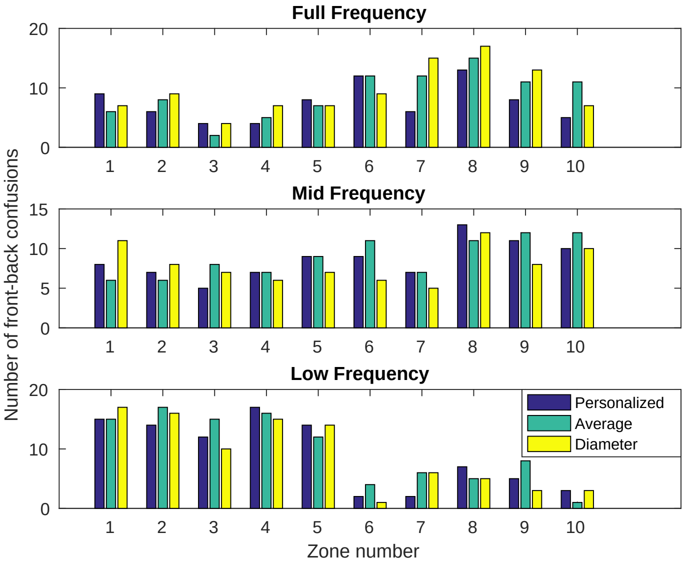


Figure 5.6: Visualization of the rate of front-back confusions

There doesn't appear to be much difference between the three HRTF sets when it comes to front-back confusion. For full frequency stimuli, there is a higher tendency towards misjudging stimuli from behind, zones 6 to 10, than in front, zones 1 to 5. This behavior is however inverse for the low frequency stimuli. Here more than half of the participants misjudged the frontal stimuli, while the back confusions are at its lowest for the data. The reason for this might be that the frontal stimuli often has a higher pitch than the back stimuli. When there only is low frequency content, there are no pitches, and nearly every sound is thus perceived as coming from behind. This indicated that low frequency spectra, corresponding to ITD, should be considered when making the personalized HRTF set to reduce front-back confusions.

Zones 1, 5, 6, and 10, the zones placed on the sides on the head, which had box plots surprisingly close to zero compared to the others, does not seem to have any more frequent cases of front-back confusion for any of the frequency ranges.

The front-back confusion data suggests that the personalization algorithm does not reduce confusion noteworthy.

Sources of Error

There are many possible sources of error in performing an experiment and analyzing the data. In the experiment part, some possible faults are there might have been unclear instruction for some of the participants, not all the head measurements may have been accurate, the participants could get tired and click randomly towards the end, or there could have been some errors in the experiment setup such as something filtering the sound stimuli. It is also hard to determine how well all the CIPIC measurements are performed.

With many lines of code there is a possibility of being more errors than the one found. Variables can have been mixed, some data can have been saved on the wrong places and so on. Some faults doing the analyzing may also have occurred. Errors may arise even though all the various aspects are being investigated thoroughly. A more satisfying result may also have been achieved with different variables and limits in the implementation.

Chapter 6

Conclusion

The *p-values* from the ANOVA test states that there are no statistical significant difference between the personalized HRTF set, average HRTF set, and the closest diameter HRTF set. This can also be seen from an overview of the box plots of the angle deviation data. There are some repeated variation between the different zones, where some that tends to result in a lower angle deviation. The zones with best accuracy are not as expected, as we have best accuracy right in front and behind us. It does however correspond with the feedback given from the test participants.

All the results from data affected by a code error suggests that the up-down head size approach used in the implementation is unnecessary.

The number of front-back confusions for low frequency content suggests that the implementation should separate ITD and ILD when making the personalized HRTF set.

Considering all the findings, the proposed methodology for obtaining personalized HRTF sets is not recommended to investigate further.

Bibliography

[1] Documentation for the UCD HRIR Files (CIPIC), 1998.

[2] J. Blauert. *Spatial Hearing: The Psychophysics of Human Sound Localization*. MIT Press, 1997.

[3] B. Xie, R.P.I. Dr. Ning Xiang, and J. Blauert. *Head-Related Transfer Function and Virtual Auditory Display: Second Edition*. A Title in J. Ross Publishing's Acoustics: Information and Communication Series. J Ross Publishing, 2013.

[4] J. Blauert. *The Technology of Binaural Listening*. Modern Acoustics and Signal Processing. Springer Berlin Heidelberg, 2013.

[5] Wikipedia. Head-related transfer function — wikipedia, the free encyclopedia, 2015. [Online; accessed 16-December-2015].

[6] CIPIC-Center for Image Processing and Integrated Computing University of California 1 Shields Avenue Davis. The cipic hrtf database, 2015. [Online; accessed 16-December-2015].

[7] Yukio Iwaya, Satoshi Yairi, and Yoiti Suzuki. Individualization Feature of Head-Related Transfer Functions Based on Subjective Evaluation, 2008.

[8] Wikipedia. Linkwitz–riley filter — wikipedia, the free encyclopedia, 2016. [Online; accessed 11-July-2016].

[9] Wikipedia. Anechoic chamber — wikipedia, the free encyclopedia, 2016. [Online; accessed 11-July-2016].

[10] Files Databases. `http://www.sofaconventions.org/mediawiki/index.php/Files`. Accessed: 2015-12-20.

[11] Philipp Paukner, Martin Rothbucher, and Klaus Diepold. Sound Localization Performance Comparison of Different HRTF-Individualization Methods, 2014.

[12] Marc M Van Wanrooij and A John Van Opstal. Sound localization under perturbed binaural hearing. *Journal of neurophysiology*, 97(1):715–726, 2007.

[13] Wikipedia. Blocking (statistics) — wikipedia, the free encyclopedia, 2016. [Online; accessed 14-July-2016].

[14] Wikipedia. Latin square — wikipedia, the free encyclopedia, 2016. [Online; accessed 14-July-2016].

[15] Jan Tro. Hearing test. Unpublished lecture note from course TTT4250 Acoustic Measurements, 2015.

[16] Durand R. Begault, Elizabeth M. Wenzel, and Mark R. Anderson. Direct comparison of the impact of head tracking, reverberation, and individualized head-related transfer functions on the spatial perception of a virtual speech source. *J. Audio Eng. Soc*, 49(10):904–916, 2001.

[17] Fang Chen. Localization of 3-d sound presented through headphone - duration of sound presentation and localization accuracy. *J. Audio Eng. Soc*, 51(12):1163–1171, 2003.

[18] R.E. Walpole, R.H. Myers, S.L. Myers, and K.E. Ye. *Probability and Statistics for Engineers and Scientists*. Pearson Education, 2011.

[19] Mathworks. Anderson-darling test, 2016. [Online; accessed 12-July-2016].

[20] Mathworks. Normal probability plot, 2016. [Online; accessed 12-July-2016].

[21] Mathworks. One-way anova, 2016. [Online; accessed 11-July-2016].

[22] Alex Reinhart. The p value and the base rate fallacy, 2016. [Online; accessed 10-July-2016].

Appendix

The code, and many results, can be found in the attachment. The folder consists of two folders, “GUI” and “Analysis”. The “GUI” folder contains the complete implementation algorithm. It can be started by running the file “personalHRTF.m” in MATLAB. Do not change the names of the other files in this folder, as the code rely on them.

The “Analysis” folder contains all the data from the experiment, except for the deleted audiometry results. This can be found in the “total” folder. It also contains the code used for the analysis of the results. The folder “Figures” contains some of the many plots that are not included in this thesis.

The rest of this appendix is about the experiment.

Table 6.1: List of Equipment used in Experiment

Equipment	**Type**	**Serial nr.**
Computer	Dell VOSTRO 3550	29872359037
Sound Card	Roland STUDIO-CAPTURE 16x10	Z1F3107
Headphones	beyerdynamic DT 990	NTNU num: Q2S HP5
PC mouse	Logitech M-U0007	1542HS0234N8
Screening Audiometer	AS 61	0169
Audiometer Headphones	SAFETY SUPPLY Co. No. 553207	Not a Number (NaN)
Sound Control	STUIO-CAPTURE Driver	Ver. 1.0.1
Implementation Software	MATLAB	Ver. R2015a
Ruler	ARDA 289 / 30	NaN
Folding rule	Hultafors 61-2-10	NaN
Thin rope	Unknown	NaN

NTNU
Kunnskap for en bedre verden

Forespørsel om deltakelse i forskningsprosjektet
«Personlig tilpasning av HRTF»

Bakgrunn og hensikt

Denne studien går ut på å teste en algoritme for å skreddersy en personlig Head-Related Transfer Function (HRTF) basert på en database med andres HRTF'er. I den forbindelse er en test av hørselen en viktig indikator for analysering av data i ettertid. Hørsel er definert som personsensitiv informasjon, så et samtykke om bruk av dataene er nødvendig.

Studien og dataene inngår som del av mastergraden til Kristian Brox

Hva skjer med informasjonen om deg?

Alle opplysningene vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende detaljer. En kode knytter deg til dine opplysninger gjennom en navneliste.

Det er kun en person, Kristian Brox, som har adgang til navnelisten og som kan finne tilbake til deg. Dataene vil destrueres etter endt prosjekt. Planlagt dato for endt prosjekt er 10. Juni 2016.

Det vil ikke være mulig å identifisere deg i resultatene av studien når den publiseres.

Frivillig deltakelse

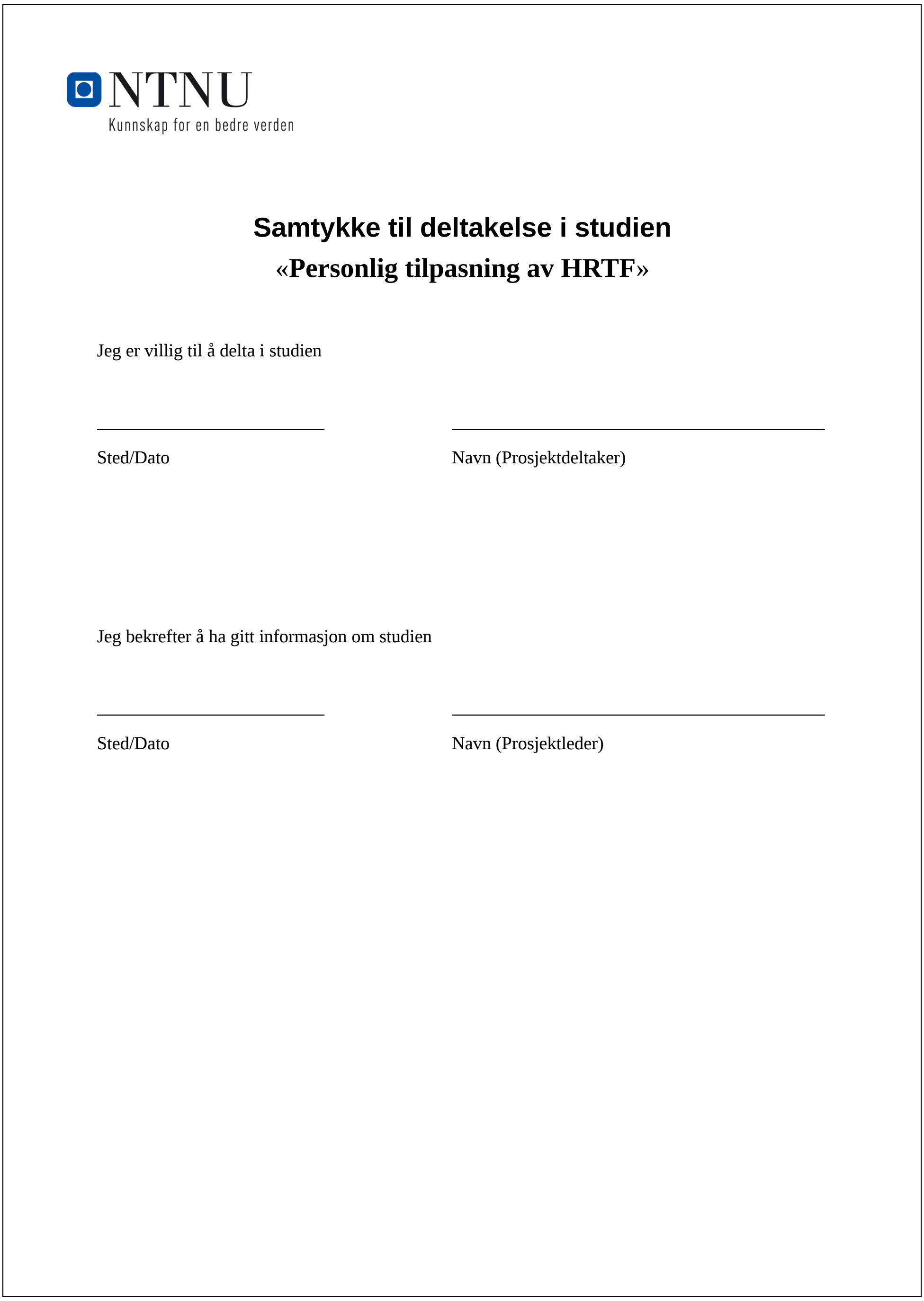
Det er frivillig å delta i studien. Du kan når som helst, og uten å oppgi noen grunn, trekke ditt samtykke til å delta i studien.

Dersom du ønsker å delta, undertegner du samtykkeerklæringen på neste side. Dersom du senere ønsker å trekke deg eller har spørsmål til studien, kan du kontakte Kristian Brox, mobil: 970 00 254, epost: krisbrox@stud.ntnu.no

Rett til innsyn og sletting av opplysninger om deg

Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg og hva utfallet/resultatet av studien blir. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede opplysninger, med mindre opplysningene allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner.

Figure 6.1: Consent form page 1 in Norwegian (Samtykkeskjema)



NTNU
Kunnskap for en bedre verden

Samtykke til deltakelse i studien
«Personlig tilpasning av HRTF»

Jeg er villig til å delta i studien

____________________	______________________________
Sted/Dato	Navn (Prosjektdeltaker)

Jeg bekrefter å ha gitt informasjon om studien

____________________	______________________________
Sted/Dato	Navn (Prosjektleder)

Figure 6.2: Consent form page 2 in Norwegian (Samtykkeskjema)