# COMPREHENSIVE MATLAB TOOL FOR HRTF MEASUREMENT AND VIRTUAL AUDITORY SPACE TESTING

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**Abstract**

**The virtual sound sources can be used for numerous purposes such as computer games, entertainment (film industry etc.) and more importantly assistive devices. The most straightforward method for the virtual sound source positioning is filtering of the input sound signal with Head Related Transfer Function (HRTF). The HRTF can be measured on the chosen subject or synthesized. When the measurement is done the HRTF must be verified whether is suitable for the purposes of the VAS. The aim of this paper is to simplify such measurements and verifications by using GUI made in the Matlab environment.**

## 1   Introduction

The virtual sound sources can be used for numerous purposes such as computer games, entertainment (film industry etc.) and more importantly assistive devices. The virtual sound sources can be positioned in a virtual auditory space (VAS) with various methods. The most straightforward method is filtering of the input sound signal with Head Related Transfer Function (HRTF). The HRTF can be measured on the chosen subject or synthesized [2], although measuring leads to better virtual sound space perception.

Our setup for the HRTF measurement (Fig. 1), described in [1] and in further chapters, was designed to be maximally portable, so is very simple. The one of problems with the setup is how to control the angle (azimuth, elevation) from which the HRTF is measured. The problem we tried to solve with help of Matlab environment.

When the measurement (or synthesis) is done the HRTF must be verified whether is suitable for the purposes of the VAS. For the testing of created VAS can also Matlab GUIs such as one described in our previous paper [3] used, but more reliable method was suggested in our paper [4]. Details about implementing of such a method in the Matlab environment are presented in this paper.



Figure 1: A picture of the experimental setup

## 2  The system design

Our experimental setup for HRTF measurement/verification consists of a custom made wide-band loudspeaker and a rotational chair (Fig. 1). The azimuth is set by rotating the chair (and the subject), elevation by elevating the loudspeaker. Due to the fact that we used only one loudspeaker to measure/verify HRTF it was crucial and very time consuming to achieve the exact azimuth between the tested subject and loudspeaker.

The rotating chair was originally equipped with a plate that had a degree scale carved into it. The chair also had a pointer which indicated the subjects azimuth. This setup required the azimuth to be read by a person (usually the experimenter), which is an inefficient way to measure HRIRs, or to measure the azimuth the subject was rotated to, and was updated to a more sophisticated setup.

The initial idea was to use the grey code to measure the location of the subject, which would require the generation of the code on the circumference of a circle, so that it could be read by a bar-code reader. But at the end a more simple and also better method was chosen to use. Instead of the grey code, which would have a constant resolution once implemented, the chair rotation would be detected with a web camera that would detect the thickness of a test image (Fig. 2) placed on the plate, where the azimuths are carved.

The Canyon CNR-WCAM820 web camera is used to detect the location. It was chosen for its simple design, which enables a simple implementation onto the chair and sufficient picture resolution.

The evaluation of azimuths, as it was mentioned above, is done by the evaluation of the width of the test image. The images are cropped and the contrast is altered so that the number of "black" pixels can be counted. From this number the azimuth is found from a lookup table, that is generated depending on the width of the test image, at the initial position during the training phase.

This setup can be used for the chair azimuth detection for both cases, measurement and testing, as is presented in next sections.
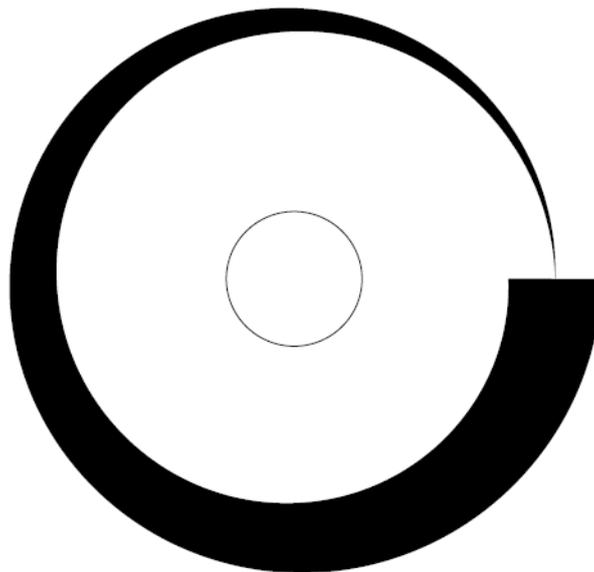


Figure 2: The test image used to detect the azimuth

## 2.1 HRTF measurement

In the case of the HRTF measurement, the subject is equipped with a pair of binaural microphones plugged in the middle ears. The test signal reproduced by the loudspeaker is at target azimuth recorded via these microphones. All of the standard methods for the transfer function measuring can be used as a test signal.

The azimuth is changed by rotating the chair the subject is sitting on. The rotation of the chair is detected by the method mentioned above and monitored by a Matlab GUI (Fig. 3) where the actual azimuth is shown. User can choose two method of the measurement, automatic and user controlled. When the automatic method is chosen the list of target azimuth with chosen azimuth step by user is created and the subject is asked to match all azimuths from the list by rotating the chair. Due to that it could be very stressful for the test subjects to match the desired azimuth without any deviation of angle there is a option for user to set up his own maximal acceptable deviation for the measurement. To avoid false positive detection of target azimuth the 5 s duty cycle is inserted in the measurement loop and then again match between the target and actual azimuth is done, if the match maintain the measurement of the HRTF could be done else the subject is asked to try again.

The operator of the measurement only informs the subject about his actual azimuth. Since this process could be another possible source of time consumption during measurement a separate window with actual and target azimuth could be open and showed to the subject on second display. Depending on the method of the HRIR measurement whole measurement can be done without help of an operator.
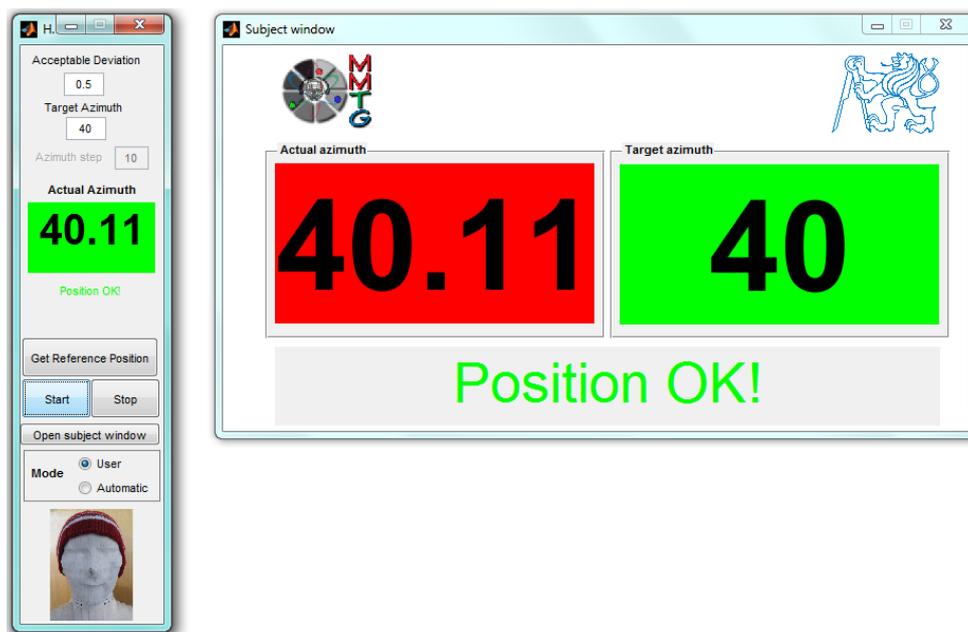


Figure 3: The GUI for azimuth detection

## 2.2 VAS verification

The setup to verify the created VAS is similar to the one used in the HRTF measurement (Fig. 1), as suggested in [4]. The only difference stays in the exchange of the binaural microphones by stereophonic earphones. The loudspeaker is used to reproduce the acoustic stimulus which acts as the acoustic pointer (reference position in space). The same stimulus but virtually positioned by filtering the original one by the measured HRTF is then presented to the subject via earphones. The subject is asked to spin the chair in order to match the position in space of both stimuli mentioned above. The principle of the method is apparent from the Fig. 4.

The test is conducted with ear-phones due to the fact, that headphones would significantly alter the sound coming from the reference speaker, which would make the task of localization more difficult. Moreover the HRIRs were measured at the entrance to the ear canal, thus it seems sensible to attempt and reproduce the binaural recording at the same place, thus eliminating the undesirable effects of the headphone transfer function. For our experiments, the Sennheiser MX 375 earphones were chosen, which have low attenuation and are small in size, so meets the requirements we stated.

Due to the available equipment at our department the testing method is limited to testing of azimuths in a fixed elevations. If the elevation of the reference could be quickly adjusted by the subject (e.g. by means of a motorized stand) the method can be also extended to the elevation testing.

The test procedure as well as the location detection are implemented in Matlab and follows the flowchart presented in Fig. 5. The procedure is based on the idea presented in [4], but was improved to increase reliability of the measurement and comfort of the subject.

At the beginning, the subject undergoes a "training phase" when all the azimuths are presented in an incrementing manner. The end of the training phase is indicated by a single beep out of the reference speaker (to make the experimenter aware as well). During the training phase, the subject shall face the reference speaker (azimuth 0), as the reference image is taken by the web camera, that will be used for the location evaluation. This means that the location evaluation is implemented in a way, that the test image and the camera do not have to be in any particular position at the beginning of the test.

Following the training phase, the subject shall try to match the position of the reference and the virtual source. In this phase, the subject is free to listen either to the reference, virtual source, or to indicate that the positions have been matched. Currently the indication is made using the keyboard:

- num1: play virtual source

- num2: play reference speaker

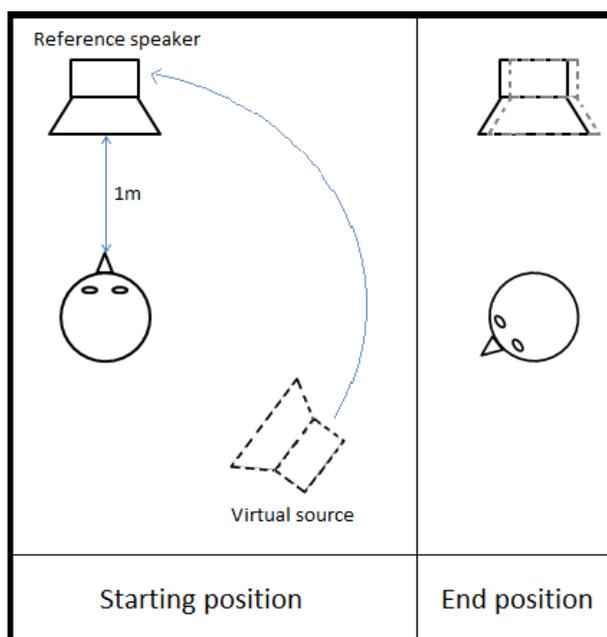- num3: location matched, move on to the next azimuth
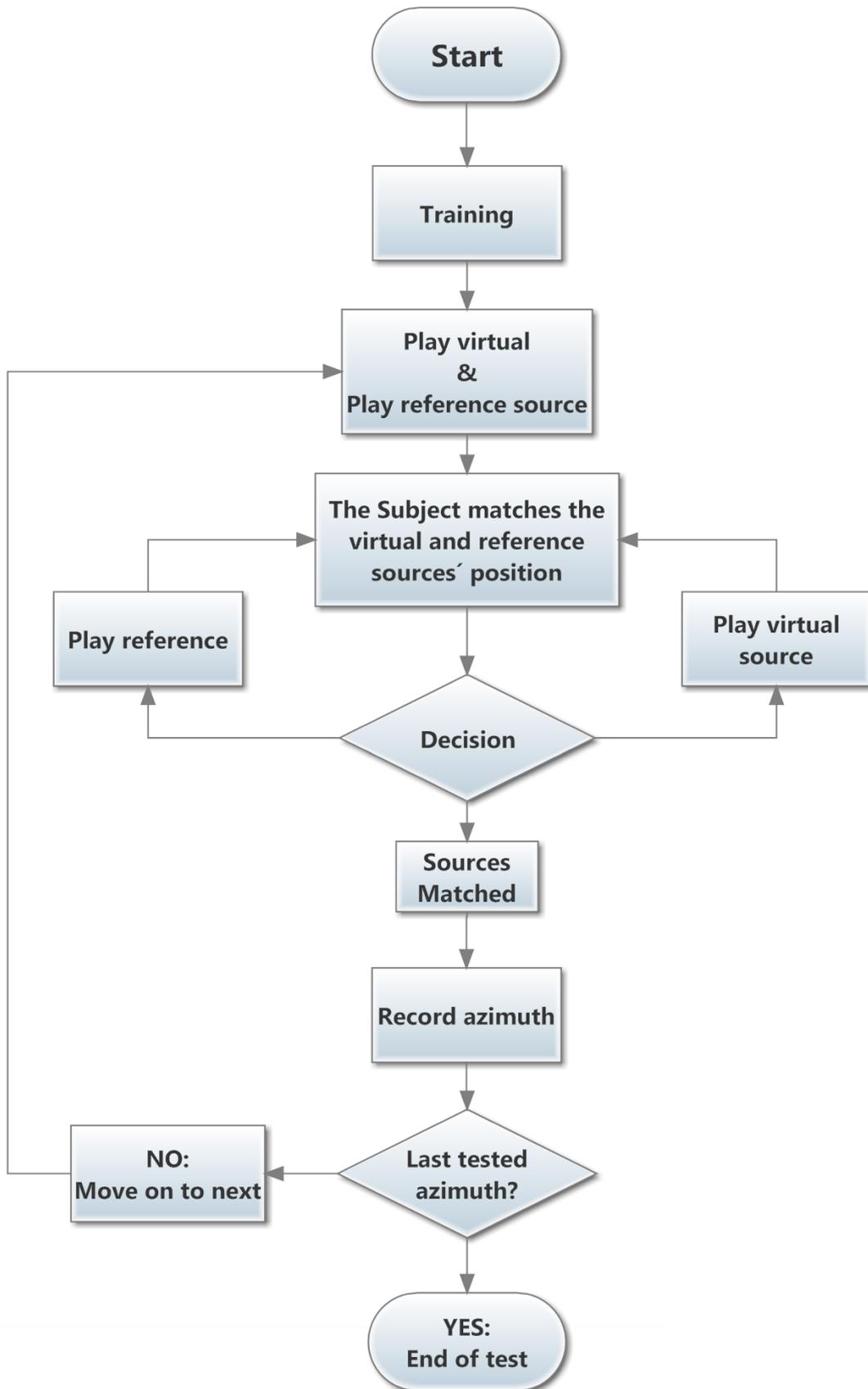


Figure 4: Principle of the localization test

Figure 5: The test image used to detect the azimuth

Whenever the location is matched, the web camera takes a snapshot of the test image, and stores it for later evaluation. A double beep indicates that all locations have been found. At this point the subject is done with the test, and the script proceeds to the evaluation of the azimuths.

Prior the test procedure, the experimenter has to set a couple of input parameters in the script. The input parameters set the subjects ID, the test accuracy, and the input binaural files.

## 3  Implementation details

The azimuth detection, GUI for HRTF measurement and the script for the test of VAS described above were implemented in the Matlab environment. During the implementation there were some issues we had to deal with.

The first task was to acquire image from the camera to determine the chair azimuth. The most straightforward solution is to use the Matlab Image Acquisition Toolbox, where the necessary functions for image acquisitions are contained. In the case the Image Acquisition Toolbox is not available, the solution depends on used operation system. For example, as we have shown in our article [5], solution like [6] can be used. In the worst case, when none of the before-mentioned solution works (e.g. 64 bit Win7 system), a external program to capture camera image (for example robotEyez [7]) can be used and then the image from the file is loaded and processed. All of the mentioned solutions are tested in our research.

The script handling the keyboard input in case of switching the real/virtual source for the VAS testing was in our implementation taken from the Matlab central [8]. The keyboard could be replaced by a joystick or any other small input device for convenience reasons.

The reproduction of the test signals requires the use of 3 audio channels (1 for the reference speaker and 2 for the earphones), however, Matlab only works with 2 channel audio by default. Again, more solutions are available, in our case was the handling of more than 2 channels solved by the use of PortAudio [9] which sent the signal into a multichannel external audio interface.

## 4  Conclusion

The Matlab implementation of the tool for measurement of HRTF and testing the algorithms for virtual sound source positioning was presented. This tool increases efficiency of the HRTF measurement and VAS testing. The tool is currently limited only to the horizontal plane (chair azimuth detection), but can be extended to vertical plane.

In the paper were also discussed and tested some ways, how to implement such a system in Matlab.

## Acknowledgement

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