Robokopp: Robotic Setup for Automated Sweet Spot Measurements with Head Simulators and Microphone Arrays

Roman Kiyan, Stephan Preihs, Jürgen Peissig

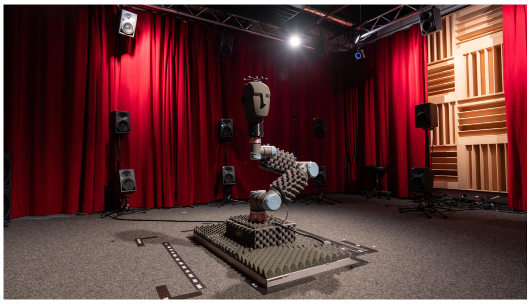
Institut für Kommunikationstechnik, Leibniz Universität Hannover

{roman.kiyan, stephan.preihs, peissig}@ikt.uni-hannover.de

Introduction

In multichannel loudspeaker reproduction, the deviation of sound field properties away from the ideal listening position – colloquially known as the sweet spot – is challenging to investigate by measurement. If several locations in a room are to be surveyed, sophisticated setups consisting of several microphones and the associated mounting hardware are typically required [1, 2]. On the other hand, if measurements with a microphone array or a dummy head are to be performed, typically only a single sensor device is available and thus needs to be moved to different positions [3]. In the latter case, manual repositioning is a tedious and error-prone process if a substantial number of positions are to be worked through, hence this measurement scenario could particularly benefit from the use of an automated positioning and measurement system. Requirements for such a system include precise positioning, reproducibility, an automated and fast measurement procedure as well as minimal influence from the equipment in terms of noise and acoustic perturbation.

This paper presents an automated measurement setup using a robot arm with custom 3D-printable mounting hardware for a Neumann KU 100 head simulator and an mh acoustics em32 spherical microphone array. The system is suitable for performing measurements in tight grids around the sweet spot in a listening room. We compare loudspeaker impulse responses (IRs) measured using this setup to measurements employing a generic microphone stand as a mounting solution, confirming the system's suitability for room acoustic measurements.



(a) Robot with Neumann KU100

(b) Robot with mh acoustics em32

Figure 1: Measurement setup in the IML.

Measurement system

The measurement system uses a Universal Robots UR5e robot arm with custom 3D printed mounting hardware to accomodate a Neumann KU 100 dummy head as well as an mh acoustics em32 microphone array at its tool flange. Figure 1 displays the measurement setup in the Immersive Media Lab (IML) at the Institute of Communications Technology [4].

The measurement software consists of two parts: Based on the ITA toolbox [5, 6], acoustic measurements as well as metadata management are performed using Matlab. Robot control is implemented using the `ur-rtde` [7] Python interface, allowing the sensor array to be navigated to different positions within the system's 0.75 m working radius. Configurable circular and rectangular measurement grids are supported along with the possibility to move through arbitrary positions in space. Optionally, motion capture data provided by a tracking system may be monitored or used for robot control. Measurements are logged and may be canceled and resumed at intermediate points in time. The custom software and 3D models of the mounting hardware are available in a companion repository to this paper [8]. The hardware and software setup of the measurement system is visualized in Figure 2.

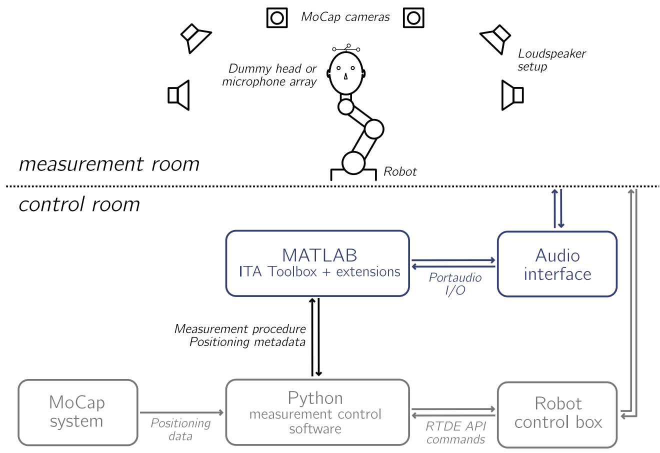
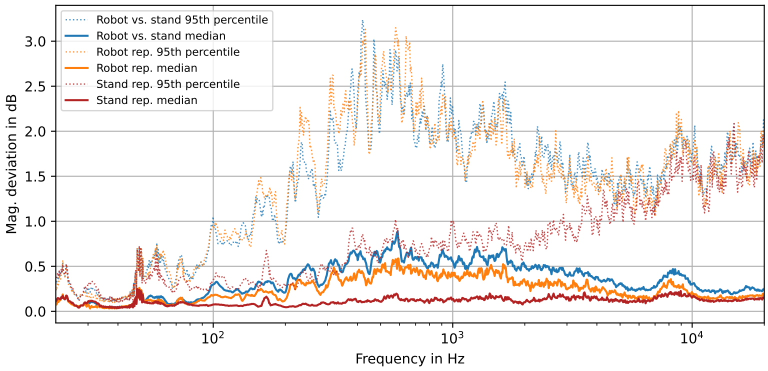
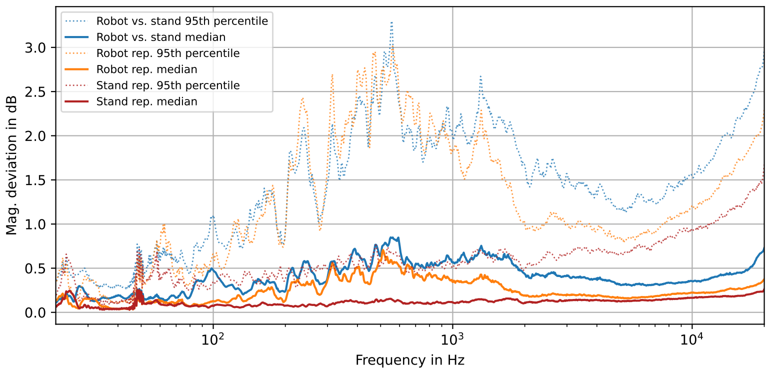


Figure 2: Block diagram of the measurement system.



(a) Measurements with Neumann KU100



(b) Measurements with mh acoustics em32

Figure 3: Median and 95th perceptile of absolute spectral differences between repeated and repositioned measurements and between measurements with the robot and a microphone stand.

Evaluation measurements

As the robot arm can be expected to provide very accurate positioning and produces negligible background noise while stationary, its acoustic influence can be considered to be limited to its effect as an object present in the proximity of the sensor array it supports. IR measurements comparing the presented system to a generic microphone stand were carried out in the IML. The listening room is equipped with 42 Neumann KH 120 A loudspeakers and four Neumann KH 810 G subwoofers. The implemented bass management with a crossover frequency of 60 Hz was enabled for the measurements.

The dummy head and the microphone array were supported in the IML's sweet spot by the robot or by a microphone stand with a cast-iron base. In this comparison, it is necessary to consider the fact that, unlike the microphone stand, the robot changes in shape as it assumes different poses to position the sensor array in different locations. With each of the setups, the KU 100 and the em32 were repositioned three times in the measurement location. For the microphone stand, repositioning was performed by removing the stand from the measurement location, re-adjusting its height and placing it back. For the robot, the base plate was moved to different locations, requiring the robot to assume different poses so as to hold the dummy head or the microphone array in the measurement location. Positioning on both the microphone stand and the robot was verified by the optical motion capture system. Logarithmic sweeps consisting of 2^{16} samples resulting in a duration of 1.4 s at the 48 kHz sample rate were used. With each of the two sensor arrays, IRs were measured from the 42 loudspeakers available in the IML to the 2 or 32 array channels. Thus the acquisition process resulted in (stand/robot × repetitions and repositioning × loudspeakers × array channels) individual IRs for each sensor array, yielding 1512 and 24192 IRs for the KU 100 and the em32, respectively.

Results and discussion

The IRs acquired using the robot and a microphone stand were compared as transfer functions (TFs) in the frequency domain. After 1/12-octave smoothing, the TFs were evaluated at 512 logarithmically spaced frequencies between 20 Hz and 20 kHz. Figure 3 compares results obtained with the robot and the microphone stand to the spectral differences across measurement repetitions and repositioning with both mounting solutions. At each frequency, the distribution of absolute magnitude deviations between conditions is represented by its median and 95th percentile and results for the KU 100 and em32 are displayed in Figure 3a and Figure 3b, respectively.

All of the spectral differences computed from the measurements exhibit distributions strongly skewed towards low absolute magnitude deviation values, with none of the median curves exceeding 1 dB. The greatest median spectral differences are observed when comparing the measurements with the robot to the measurements with the microphone stand whereas the differences between repeated measurements across repositionings of both sensor arrays are lowest. This is to be expected due to the robot's changing pose across repositionings. This inherent discrepancy between the microphone stand and the robot is particularly apparent when observing the curves representing the 95th percentile of spectral differences: For repeated measurements and repositioning with the microphone stand, the 95th percentile curves indicate increased uncertainty towards higher frequencies. A similar trend is observed in the 95th percentile curves for the robot. However, when comparing measurements obtained with the robot to other robot or microphone stand measurements, increased spectral deviations as well as individual peaks and notches can be observed, especially between approximately 300 Hz and 1 kHz. As the wavelengths associated with this frequency range are consistent with the robot's geometric dimensions, these perturbations may also be explained by its non-constant shape. Thus it can be concluded that, while some robot poses can be somewhat disadvantageous in terms of the robot's acoustic influence, the system is suitable for performing measurements whose results are comparable to results obtained with the sensor array placed on a simple stand.

Summary and Outlook

A system for automated acoustic measurements using a robot arm was developed and implemented in a listening room. The system's influence on the measured acoustic TFs was evaluated, confirming its suitability for acoustic measurements. The measurement system can be used for the acquisition of location-dependent IR datasets in dense spatial grids with subsequent acoustic analysis characterizing the sweet spot for a given listening room and reproduction system in terms of various sound field parameters computed from these real-world high-resolution IR measurements. The publication of a dataset measured in the IML is planned by the authors.

References

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