Autonomous Robotic Platform To Measure Spatial Room Impulse Responses

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Motivation

Spatial Room Impulse Responses (SRIRs) provide information about the acoustic properties of a room, such as how sound waves reflect and reverberate within the space. However, the specific SRIR obtained is dependent on the position of both the sound source and the receiver within the room. Measured SRIRs can serve as a valuable reference for acoustic simulations or for the parametrization of room acoustics in virtual environments. By using the measured SRIRs as a starting point, researchers and engineers can better understand and model the acoustics of different rooms or spaces.

In order to capture the acoustic properties of a room in high detail, it is often necessary to take measurements at many different positions throughout the room. Doing this manually can be tedious and labor-intensive, making it difficult to obtain a complete picture of the room's acoustics.

Robotic platforms have already been used in other scientific work for similar purposes, but they either lack mobility [1, 2] or lack navigation capabilities to allow a systematic approach of positions [3]. The aim of this project is therefore to realize a system for the autonomous measurement of SRIRs in a systematic manner using a mobile robotics platform. A similar system has been shown in [4], using dummy heads instead of microphone arrays.

Hardware

Robotic Platform

As a robotic platform a *TORY v2* by *MetraLabs* is beeing used. The robot's two-wheel drive allows for free positioning on a plane while using a 2D-LIDAR scanner and odometry data to determine its location. The data from the LIDAR scanner is also used to detect obstacles in its path and avoid collisions. In addition, it has a tactile safety edge that can detect contact with objects, triggering a safety stop to prevent damage or injury. The maps for navigation have to be pre-recorded by a human operator.

In a previous study, the robot's localization accuracy was determined to an average of 2.7 cm in translation and 0.7° in rotation. In addition it can approach a target position with an accuracy of 3 cm in translation and 0.6° in orientation. [5]

Battery life averages around 8 hours per charge, but highly depends on the distance traveled by the robot. Recharging is done automatically by docking on a charging station. Charging the battery from 20% to 100% takes approximately 2 hours.

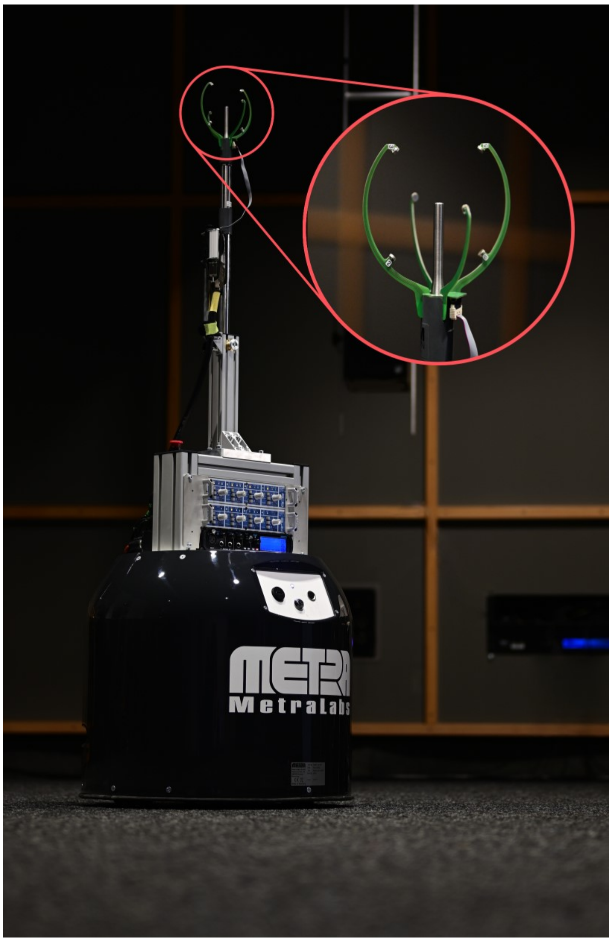

Figure 1: Picture of the robotic platform with mounted microphone array.

Microphone Array

The robot, as shown in figure 1, is equipped with a microphone array consisting of six satellite microphones mounted around an Earthworks M30 measurement microphone. The satellite microphones are spherically distributed in a diameter of 10 cm with the measurement microphone in the center. The whole array is placed in the center of the robotic platform and can be manually adjusted between 112 cm and 175 cm from the ground.

Based on the Spatial Decomposition Method (SDM) [6] the array allows the estimation of SRIRs from Exponential Sine Sweep (ESS) recordings. In addition the RIRs based on the recordings of the measurement microphone can be used for classical one dimensional room acoustics analysis. The test signals are played back over loudspeakers placed at fixed positions in the room which are connected to an external computer. Currently there is no synchronization between the loudspeaker playback and recording, but for the estimation of many acoustic parameters this is not necessary.

Software

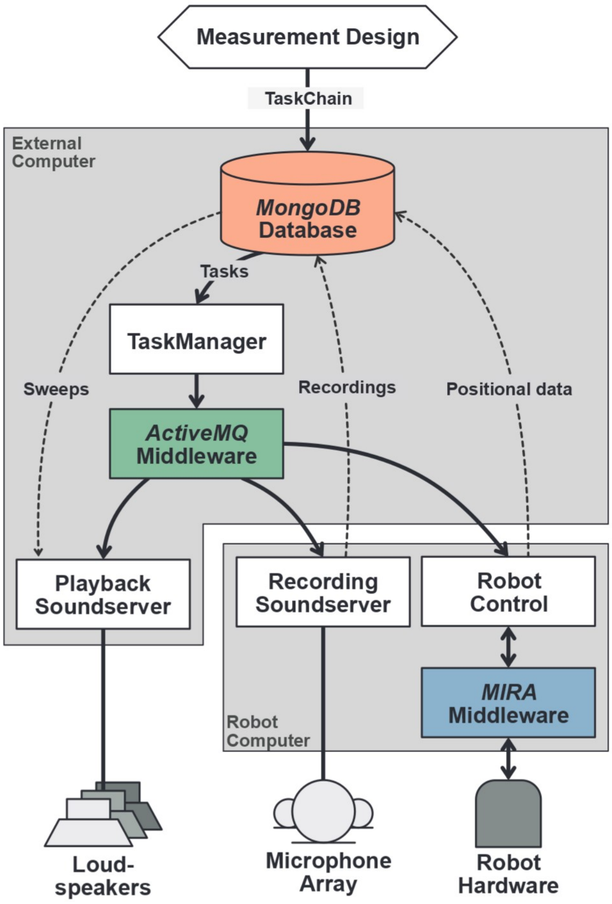

Figure 2: Block diagram of the system components and workflow to control the robot system.

The software components are built around a central database containing the *TaskChain* as shown in figure 2. As the basic database software *MongoDB* [7] is used.

The TaskChain is a linked list of *Tasks*, which are database entries containing the parameters for different *Services* to fulfill the measurement. Said parameters are for example the position and orientation for the robot to approach or the sweeps to play over the loudspeakers. In addition to that, the collected data is stored back in the TaskChain, for example the sweep recordings or the execution time. The TaskChain can be modified during runtime, allowing for example the insertion of tasks to load the battery if the charge is critical or putting back a task if the target is temporarily unreachable for the robot.

The *TaskManager* distributes the Tasks to the corresponding Services. Currently the Services are the Soundservers for playing back and recording audio and one to control the robotic platform itself by communicating with the robots middleware *MIRA* [9]. Through the modular design of the TaskChain it is easily possible to add new Services for future use cases. The communication between the TaskManager and the Services is done via the ActiveMQ middleware [8], allowing communication over IP-Network. Aside from the mentioned software, all implementations were done in *Python 3* [10].

Modus Operandi

Before the measurement can begin a 2D map of the respective room has to be recorded using the robots LIDAR scanner. In principle, the measurement positions can be chosen arbitrarily, but in the context of reference measurements, it was decided for uniform grids. Based on the robot's map such a uniform grid can be adapted to the rooms geometry to prevent errors and to allow accurate planning.

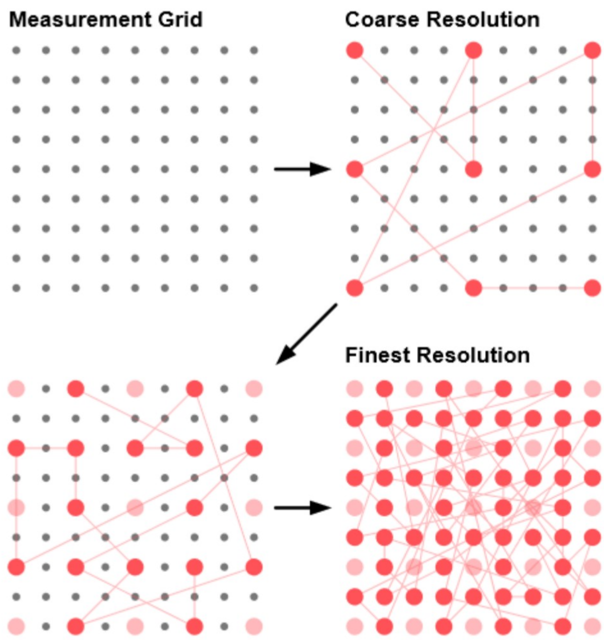

Figure 3: Approach of the measurement positions in a partially random order. Starting with a coarse resolution in the Small gray circles show the defined measurement positions, deep red circles indicate the positions that will be approached in the current step and light red circles indicate the positions that were already approached in a previous step.

During the actual measurement the positions are approached in a partially random order as shown in figure 3. In a first step the positions in a coarse resolution are approached, but in a random order. In the following steps the resolution is increased until the target resolution is reached.

In a previous study it was shown, that approaching the positions in a non-random fashion, one after another in a straight line, leads to a systematic deviation increasing towards the end of the line [5]. The partially random order was chosen to prevent temporal invariances from affecting neighboring measurements. It also has the advantage that, should a fatal error occur later in the measurement, the room was scanned as evenly as possible.

Example Measurement

The first measurements with the robotic system were conducted in the listening lab of Technische Universität Ilmenau. The room measures 8.4 m × 7.6 m × 2.8 m and is acoustically treated according to *ITU-R BS.1116-1*.

A 5 m × 6 m grid of measurement positions was defined in the center of the room, with a pitch of 25 cm between positions. With cutouts in the measurement grid to consider positions that were blocked by obstacles, a total of 466 positions were approached.

5 Loudspeakers were placed in and around the measurement grid. The loudspeakers and microphone array were mounted at a height of 1.75 m. At each position 3 ESS signals were played over each loudspeaker one after another and recorded by the microphone array mounted on the robotic platform.

This adds up to a total of $466 \cdot 5 \cdot 3 = 6990$ recorded sweep signals. Figure 4 shows the Early Decay Time (EDT) values calculated from the recordings of the measurement microphone for one loudspeaker.

The whole measurement took two days to complete including charging time, some interventions by a human supervisor to fix minor errors and other breaks. The pure measurement time, meaning the time for target approach and sweep recordings, was about 29 hours. The battery had to be recharged 3 times for around 2 hours each.

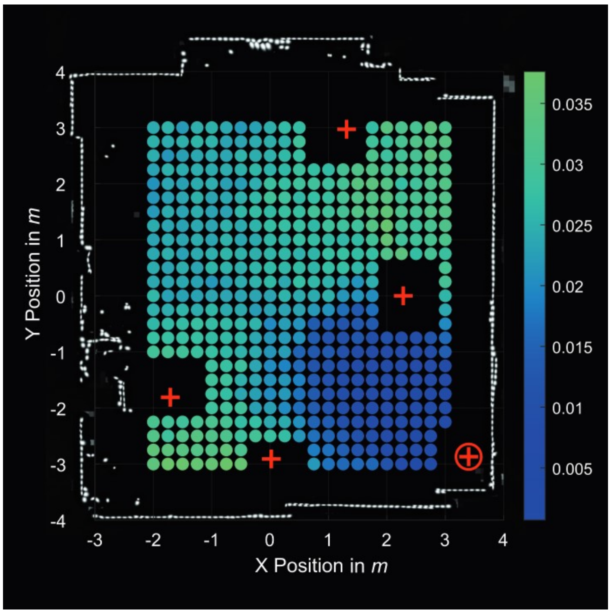

Figure 4: Calculated EDT values of the example measurement using the robotic platform. The red encircled cross marks the loudspeaker used for the example calculations. The red crosses without circle mark the other loudspeakers used in the measurement. The white floor plan is a visualization of the robots LIDAR map.

Outlook

The current state of the project allows the creation of spatial high-resolution reference data sets for acoustic analyses using a mobile robotic platform. The next development step will be the implementation of a robust error detection system based on the acoustic measurements already performed. Hereafter the plan is to measure reference data sets in various rooms to gain a better understanding of room acoustics and its spatial dependencies.

In the future this will eventually allow the autonomous determination of measurement positions during runtime by the robotic system, e.g. by evaluating the floor plan or by analyzing a few initial measurements. This is intended to shorten the measurement time, especially in large rooms.

Acknowledgment

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