URTIS: A SMALL 3D IMAGING SONAR SENSOR FOR ROBOTIC APPLICATIONS

Thomas Verellen, Robin Kerstens, Dennis Laurijssen, Jan Steckel
CoSys-Lab – University of Antwerp, Flanders Make Strategic Research Centre

Sonar Imaging

Autonomous vehicles rely on optical sensors to perceive their environment. However, these sensors tend to fail in environments where a lot of airborne particles are present such as fog or dust. This disturbed data could be complemented with data gathered from ultrasonic sensors, which use acoustic waves that are able to pass through medium distortions relatively unhindered. CoSys-Lab has previously developed the embedded Real Time Imaging Sonar (eRTIS), a high-accuracy 3D sonar sensor based on sparse and pseudo-random microphone arrays [1–3]. The microphone array in the eRTIS sensor consists of a pseudo-random 32 microphone array placed using Poisson Disc-Sampling. To form acoustic images, the eRTIS sensor uses Delay-And-Sum (DAS) beamforming to solve the Direction Of Arrival (DOA) of the reflected signal. Recently, a smaller version of the sonar sensor (µRTIS) has been developed to satisfy the need for a smaller 3D imaging sonar. The µRTIS consists of 30 microphones placed in a Uniform Rectangular Array (URA) and uses MUltiple Signal Classification (MUSIC) to solve the DOA problem. It also features a smaller speaker to realise the sonar sensor as compact as possible, reducing its size to 5.7 cm by 4.6 cm from 12.2 cm by 10.8 cm compared to the original eRTIS sensor, which makes the µRTIS very attractive for all kind of mobile robotic applications in need for cost-effective 3D environmental perception which do not rely on optics.

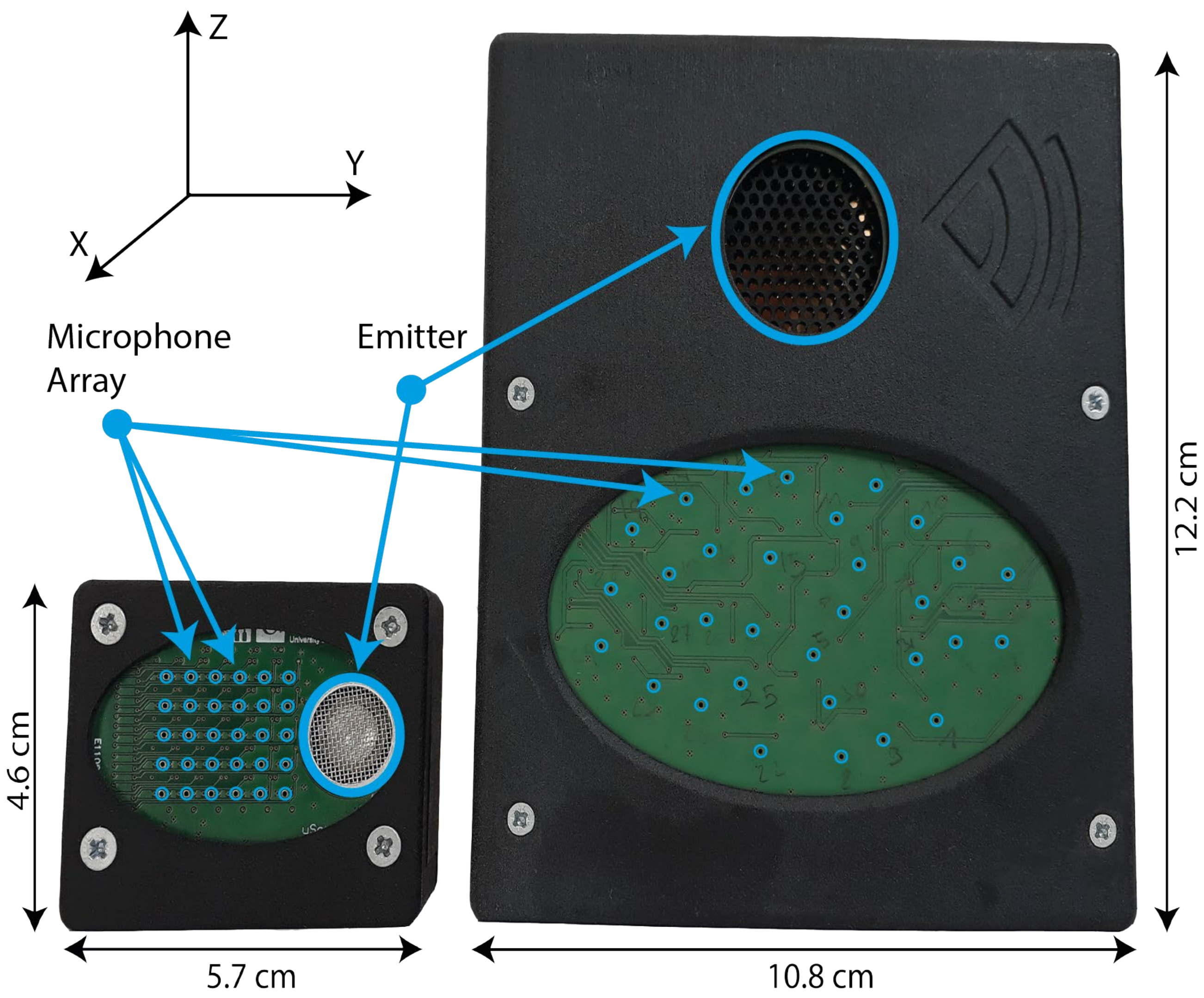

Figure 1: Side by side view of the µRTIS (left) and the eRTIS (right), which are two 3D imaging sonar sensors developed by CoSys-Lab. The microphone array in the eRTIS sensor consists of a pseudo-random 32 microphone array placed using Poisson Disc-Sampling, while the microphone array in the µRTIS consists of a 30 microphone URA of 5 by 6.

Hardware

The µRTIS (figure 1) is an active 3D sonar sensor consisting of a small ultrasonic transducer and an array of 30 Micro-Electro-Mechanical System (MEMS) microphones which are placed in a URA of 5 by 6. We have chosen a URA to create the µRTIS as compact as possible and to allow for high resolution imaging techniques to be applied. We achieved this by placing the microphones with a spacing of 3.85 mm, which means we can spatially localize ultrasound sources with frequencies up to 44.545 kHz. To emit our signal we use a Prowave 400ST160. This piezoelectric ceramic disc has its highest sensitivity around 40 kHz and a bandwidth of 2 kHz which perfectly matches the placement of our microphones. These component and dimension changes also lower the fabrication cost of the µRTIS compared to the eRTIS. The final size of 5.7 cm by 4.6 cm enables the µRTIS to be used for all kinds of mobile application e.g. drones or other robotic vehicles.

Processing

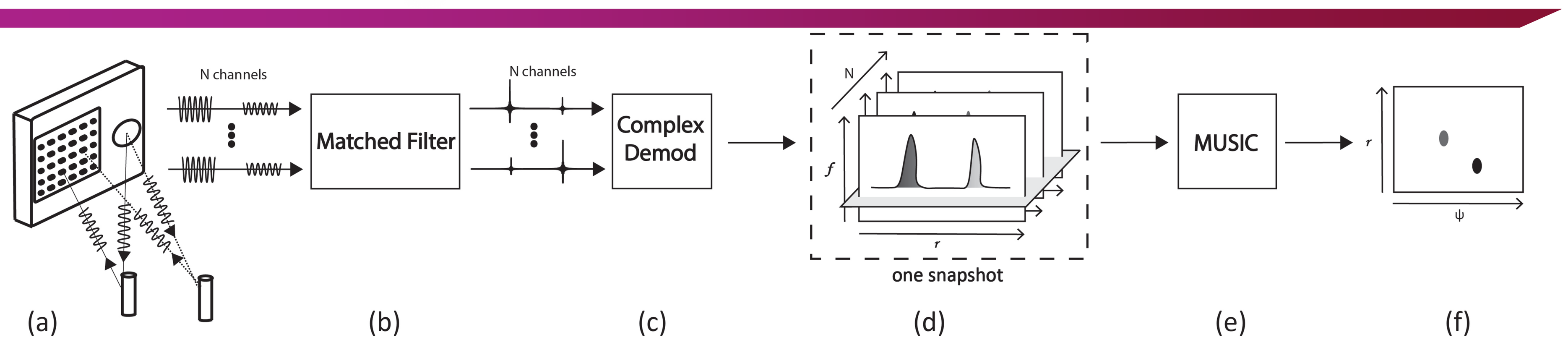

Figure 2: Schematic overview of the steps that are executed by the signal processing flow. An adapted version of the processing flow in [3] where the Bartlett beamformer is replaced by the MUSIC algorithm, the eRTIS replaced by the µRTIS and the STFT by the complex IQ-demodulation. (a) a µRTIS 3D imaging sonar performs an active measurement of the environment. (b) A matched filter used to amplify the difference between the received signal and background noise. (c) Using complex IQ-demodulation we can extract the frequency information of the recorded signal and estimate the range of the reflections (d) The one snapshot that will be used consists out of the range-(single)frequency information across multiple channels, s(t). (e) The algorithm used for beamforming is the MUSIC-algorithm. (f) Finally we get a 3D image showing the location of the reflectors with ψ being a function dependent of the azimuth and elevation of the resolved source.

3D Simulation

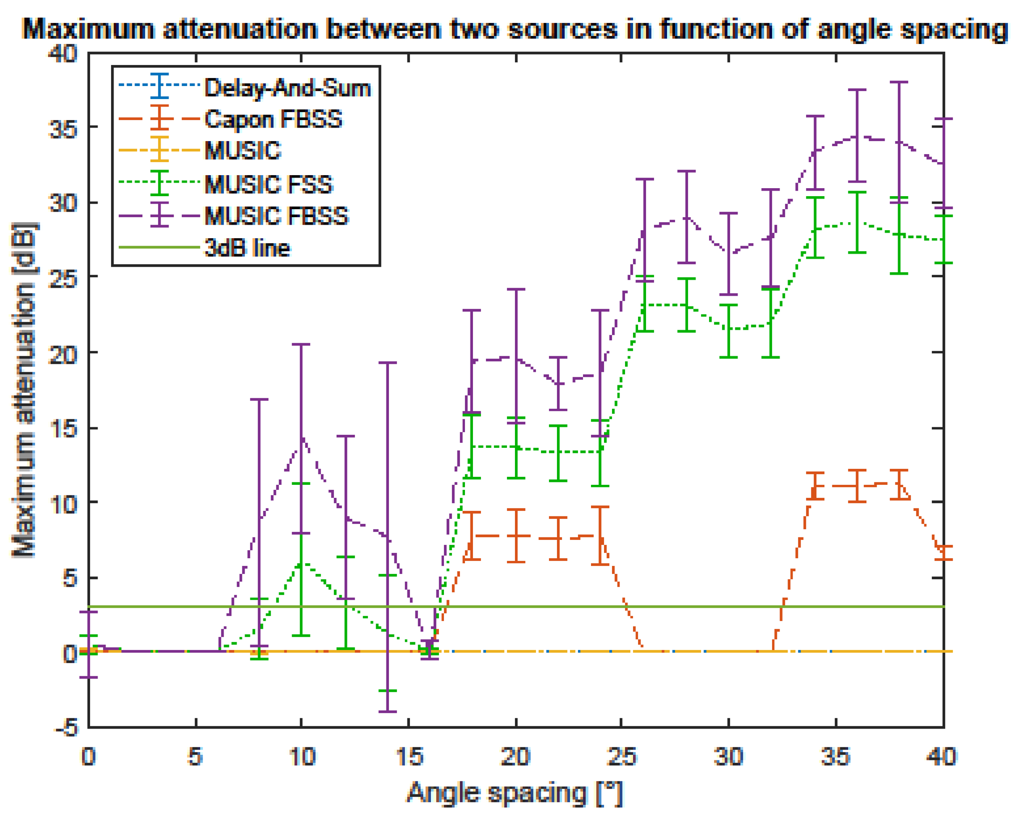

Figure 3: Maximum attenuation between two sources in function of angle spacing with five different DOA-algorithms. To gather the data a simulation of the µRTIS was used. The sources are symmetrically placed right in front of the sensor at a distance of 1 m. Only one snapshot is used with a SNR of 10 dB.

To theoretically validate our chosen DOA estimator, we simulated the µRTIS in a situation with two reflectors present. The reflectors were symmetrically placed in front of the µRTIS at a distance of 1 m. We varied the spacing angle in between the two sources and were interested in the maximum attenuation between them. Every experiment was repeated 20 times, the results are visible in figure 3. The compared algorithms were Delay-And-Sum, Capon using Forward-Backward Spatial Smoothing (FBSS), MUSIC, MUSIC using Forward Spatial Smoothing (FSS) and MUSIC FBSS. Figure 3 shows the need of spatial smoothing for the MUSIC algorithm. MUSIC without spatial smoothing and DAS both fail to see a difference between the two sources. Once a spatial smoothing scheme is used, the performance increases drastically. It further shows the ability of MUSIC to outperform Capon.

3D Mapping Results

To validate the real-world performance of the µRTIS in an acoustic imaging task, we attached it to a small radio guided robot that was driven through a narrow corridor. We captured data at 10 Hz and calculated acoustic images using DAS and MUSIC, using the processing scheme described in figure 3. A video of the entire dataset is available at [4]. In figure 4 two exemplary acoustic images from this dataset are shown. This figure shows the difference between the imaging of DAS and the MUSIC algorithm. The most important one being some artefacts right in front of the robot (the sources closest to [0, 0]) when using DAS. We know these are artefacts since the robot was driven trough the centre of 2 m wide hallway and never straight at a wall. MUSIC does not show these artefacts. Furthermore, the correct reflectors that are resolved by the MUSIC algorithm also show a higher dynamic range and narrower Point Spread Function (PSF). Figure 4 further shows the effect of the multipath phenomenon. The emitted signal is reflected and reaches our sonar sensor by multiple paths. This results in several sources being resolved behind each other, these ghost reflectors are indicated by the white circles in figure 4. The suppression of these multipath signals is an interesting topic for future research. Although there is many research available regarding multipath and sonar, application of underwater sonar. Where it models the signal in such a way it takes account of the multipath propagation due to the sea-surface and seabed reflections or the incoherency between different reflection signals. This is not applicable to our in-air sonar where we are not certain the environment is limited by two planes. This research is mostly based on the application of underwater sonar.

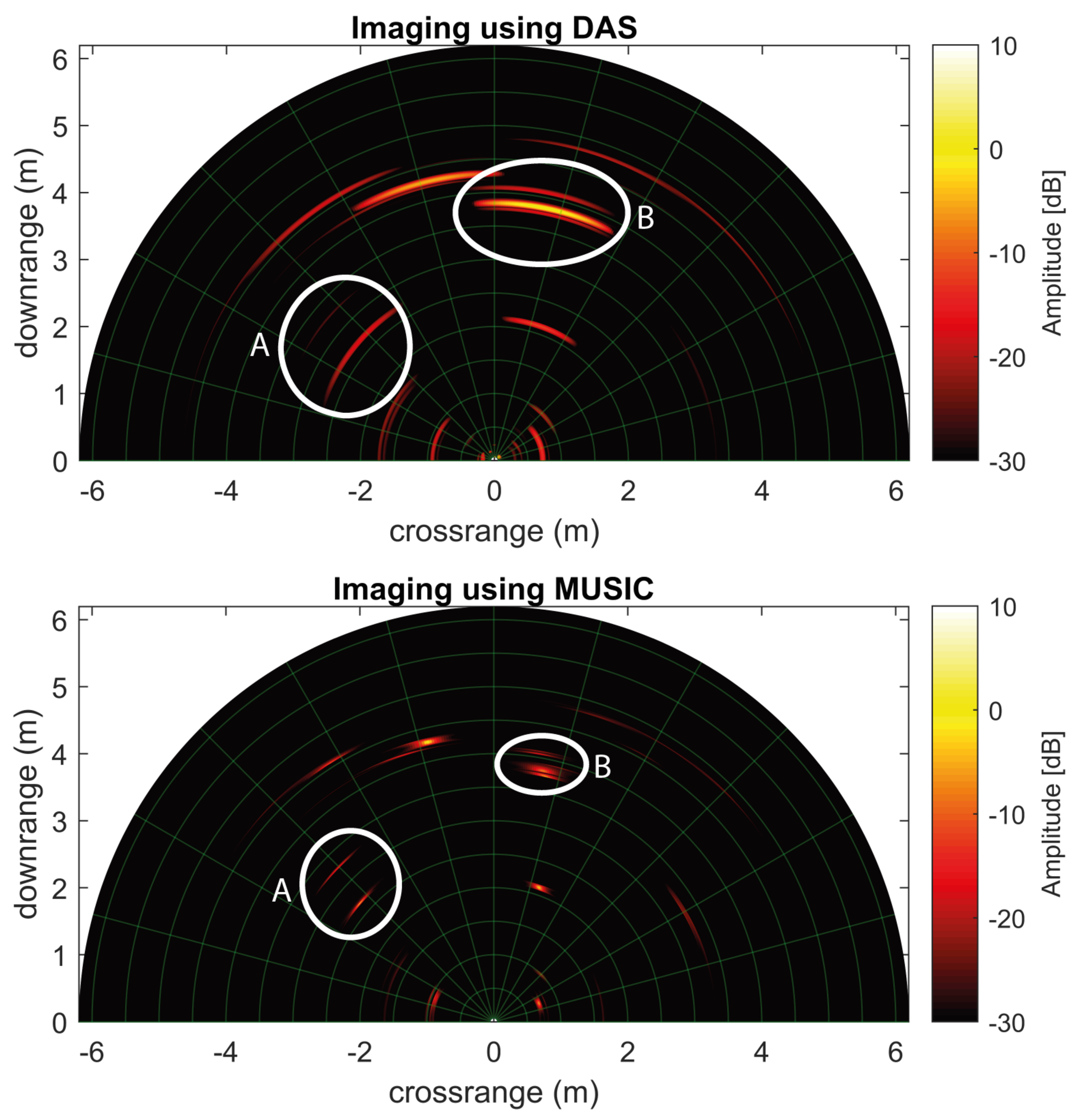

Figure 4: Spatial images of the µRTIS, an in-air 3D sonar sensor developed by CoSys-Lab, using two types of beamformers. The recording is a snapshot from a small robot driving through a narrow hallway. The µRTIS is placed at [0, 0]. The white circles (A and B) indicate matching reflections for both beamformers, illustrating the improvement of the PSF of the resolved reflections.

Key References

[1] Robin Kerstens, Dennis Laurijssen, and Jan Steckel, “Low-cost one-bit MEMS microphone arrays for in-air acoustic imaging using FPGA’s,” in 2017 IEEE SENSORS. oct 2017, pp. 1–3, IEEE.
[2] Robin Kerstens, Dennis Laurijssen, and Jan Steckel, “eRTIS: A Fully Embedded Real Time 3D Imaging Sonar Sensor for Robotic Applications,” in 2019 International Conference on Robotics and Automation (ICRA). may 2019, pp. 1438–1443, IEEE.
[3] Jan Steckel, Andre Boen, and Herbert Peremans, “Broadband 3-D Sonar System Using a Sparse Array for Indoor Navigation,” IEEE Transactions on Robotics, vol. 29, no. 1, pp. 161–171, feb 2013
[4] Jan Steckel, “https://www.youtube.com/channel/UC9MzqwVf0ZFmt19lJMAgVxQ,” 2019.

University of Antwerp - Faculty of Applied Engineering
Groenenborgerlaan 171 building U, 2020 Antwerp, Belgium

Universiteit Antwerpen CoSys-Lab Constrained Systems Lab University of Antwerp FLANDERS MAKE DRIVING INNOVATION IN MANUFACTURING