Poster: Ultra-low-power Acoustic Imaging

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ABSTRACT

This poster presents the design and implementation of *SPiDR*, an ultra-low-power acoustic imaging system. This imaging system produces a cross-sectional map of the field-of-view using only one speaker/microphone pair. It leverages the fact that sound's interaction with small structures can project spatially coded signals on a region at a fine granularity. We create a 3D-printed passive filter, called a stencil, that can image the scene with a single omnidirectional source and sensor. With spatially coded signal, the system receives a linear combination of the reflections from nearby objects and applies a novel power-aware depth-map reconstruction algorithm. *SPiDR* consumes only 10mW of power to generate a depth-map in real-world scenario with over 80% structural similarity score with the scene.

1 OVERVIEW

Scene imaging for understanding the environment for navigation is crucial for robotics. Widely adopted methods have been developed for scene perception purpose. Depth camera is one of the most effective approach. Other strategies include scanning the surroundings and generating a depth-map of the scene using lidar, radar, or sonar based techniques. However, these techniques require using mechanical maneuver or electronic beam-steering using an array of sensors – leading to higher energy requirements. Therefore, despite tremendous advancement in engineering, these techniques are not directly applicable in micro-robotic systems for their unique constraints of limited energy source, small size, limited computational power, and the requirement of low-cost manufacturing (SWaP-C constraints). A survey indicates that only 1030mW of power remains available for sensing in typical micro-robot systems after allocating power to the actuators for locomotion. Needless to say, these systems contain significantly limited computational resources.

In this poster, we present *SPiDR*[1], an ultra-low-power acoustic spatial sensing system capable of generating an accurate depth-map of nearby objects, with only one pair of speaker/microphone. Also, we do not consider mechanical steering for scanning the scene with one sensor. We achieve this by using a spatially coded signal that sends unique patterns of signal in each direction. Figure 1 gives an overview of the system. We design a 3D-printed cover for the speaker, called a stencil, that divides the speaker's output into multiple replicas by passing it through small internal tubes. These tubes have different lengths, thus induce diverse phase delays and therefore their superimposition leads to a specific amplitude and phase of the received signal. A unique combination of the path lengths can produce a unique coded pattern in 3D space. The lengths of these internal tubes are carefully calculated to channelize the signals through different time-delayed paths before releasing them through separate output sound holes pointed at different spatial directions. When the signals encounter the edge of the holes, diffraction happens to transmit each replicas to a wide angle. These delayed and diffracted replicas interfere with each other and create complex but predictable patterns at different points of the scene. With this specific code to the 3D points in space, occupied voxels can be separated through processing to convert them to a point cloud of objects in the scene. Our previous work Owlet [2] shows the possibility of using acoustic microstructure to embed directional clues to the signal recorded by a microphone. Owlet detects the angle of arrival of incoming sounds, while *SPiDR* captures a cross-sectional depth image of the scene. Refer to our MobiSys 2022 paper [1] for a detailed system description and evaluation.

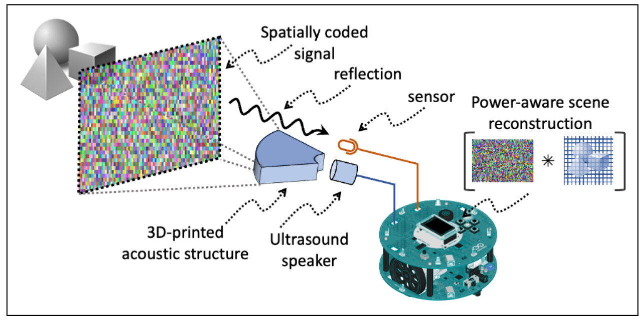

Figure 1: *SPiDR*, an ultra-low-power acoustic spatial sensing system for mobile robots. The system requires a single transducer for sensing and uses a 3D-printed microstructure for projecting spatially coded signals.

[1] SPiDR stands for Structure-assisted Perception, Detection, and Ranging