RoboSwarm

An Acoustic Neighbor Identification Platform for Swarm Robotics

ELECOMP Capstone Design Project 2026-2027

Sponsoring Company:

Intelligent Control & Robotics Lab. (ICRobots)
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Entity Overview:

For more than 50 years, robots have been confined to manufacturing facilities and other specialized application fields. But robotics technology is getting ready for widespread adoption and integration in the human society. New applications of mobile robots, both for professional use and for the general public, are being invented at an increasing pace. At the same time, new challenges arise when robots break free from the known controlled environment of factories to move into the real wide world.

The Intelligent Control and Robotics (ICRobots) laboratory at the University of Rhode Island is a world class research lab specializing in mobile and aerial robotics and multi-robot systems. Our vision is to bring cutting-edge robotic technology to application and consumers, to contribute to a better future.

The ICRobots lab includes three directing faculty members, from 2 different departments and several graduate and undergraduate students, with $2M+ in research funding from many state and federal agencies.

Technical Director(s):

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Project Motivation:

The next generation of robotic systems will increasingly rely on groups of robots working cooperatively rather than on a single autonomous platform. Robot swarms have the potential to accomplish tasks that are difficult or impossible for individual robots, including environmental monitoring, warehouse automation, search and rescue, precision agriculture, and planetary exploration. A key requirement for cooperative behavior is the ability for robots to detect and identify neighboring robots using inexpensive onboard sensors.

Most existing multi-robot systems rely on wireless communication, cameras, or LiDAR to identify nearby robots. While effective, these approaches either require significant computational resources, external infrastructure, or are susceptible to communication congestion as swarm size increases.

An alternative approach is to use acoustic signaling. Each robot continuously emits a unique audio tone while simultaneously listening to its environment through a microphone. By analyzing the received acoustic spectrum, a robot may identify which neighboring robots are present based on the frequencies detected. Such a system would require minimal communication bandwidth, inexpensive hardware, and relatively simple signal processing.

The goal of this project is to investigate the feasibility of this concept using a small swarm of custom-designed mobile robots. The project will establish whether reliable robot identification through acoustic signatures is practical using low-cost embedded hardware and consumer-grade audio components. The resulting platform will also serve as a reusable research testbed for future work on swarm robotics within the ICRobots laboratory.

Concept Design:

The project consists of designing and building a compact robotic platform based on an ESP32 microcontroller. Each robot will include:

- custom PCB
- ESP32 microcontroller
- microphone
- miniature speaker
- rechargeable battery
- USB-C charging interface

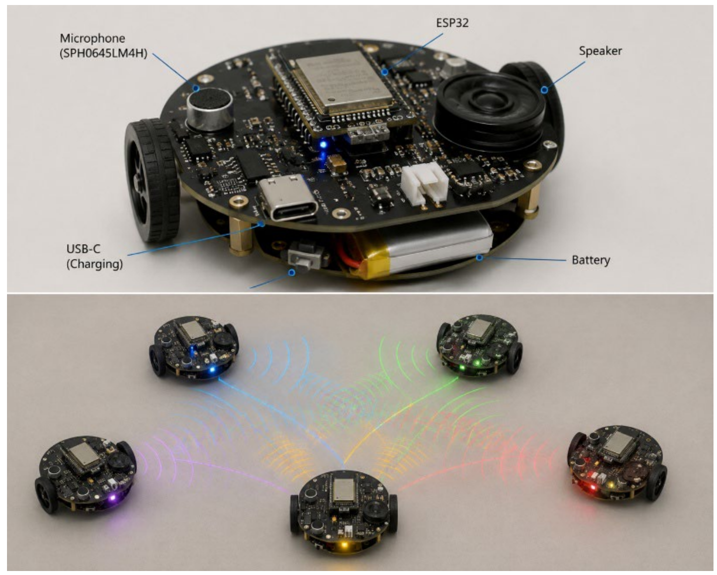

***Figure 1**: Conceptual design of the proposed RoboSwarm platform. **Top:** Hardware layout of an individual robot. **Bottom:** Example of acoustic neighbor identification within a small robotic swarm.*

Each robot will continuously generate a unique tone while simultaneously sampling audio through its microphone. The ESP32 will periodically compute the Fast Fourier Transform (FFT) of the received audio signal and identify neighboring robots from the spectral peaks corresponding to each assigned frequency.

Approximately three to five identical robots will be fabricated to evaluate the scalability and robustness of the approach. The platform may optionally be expanded with differential-drive mobility, wheel encoders, and infrared obstacle sensors for future swarm navigation experiments.

Anticipated Best Outcome:

The project will produce a compact, battery-powered robotic platform specifically designed for swarm robotics research. Students will design a complete PCB integrating the ESP32, microphone, speaker, power management circuitry, battery charging electronics, and expansion headers for future sensors.

Three to five identical robots will be manufactured and assembled. Each robot will continuously emit a unique acoustic beacon while simultaneously detecting neighboring robots using FFT-based signal processing. Experimental validation will characterize:

- maximum reliable detection distance;
- robustness under multiple simultaneous transmitters;
- effects of ambient noise;
- frequency resolution and identification accuracy;
- influence of robot orientation;
- influence of room reverberation;
- computational load on the ESP32.

The project is expected to determine whether inexpensive acoustic hardware can reliably provide neighbor identification for small robotic swarms.

If time permits, the robotic platform will be extended beyond ABO with:

- differential drive motors;
- wheel encoders for odometry estimation;
- infrared proximity sensors acting as virtual bumpers.

These additions would transform the system into a complete swarm robotics platform suitable for future undergraduate and graduate research projects.

The final deliverables will include:

- complete PCB schematic;
- PCB layout;
- assembled robots;
- embedded firmware;
- experimental evaluation;
- documentation and user guide;
- recommendations for future improvements.

Project Details:

The project is divided into several major tasks.

1. System Design

Select suitable hardware components including:

- ESP32 development module or bare ESP32
- MEMS or electret microphone
- miniature speaker
- audio amplifier
- lithium battery
- voltage regulation
- USB-C connector

Power consumption and PCB size should be considered throughout the design process.

2. PCB Design

Design a compact circular PCB with a target diameter of approximately 15 cm or smaller.

The PCB should integrate:

- ESP32
- microphone interface
- speaker amplifier
- battery connector
- USB-C charging
- expansion headers
- power switch
- status LEDs

3. Embedded Software

Develop firmware capable of:

- generating a continuous tone assigned uniquely to each robot;
- sampling microphone data using the ESP32 ADC or digital microphone interface;
- computing FFTs in real time;
- detecting spectral peaks corresponding to neighboring robots;
- reporting robot IDs through serial output or onboard LEDs.

Signal processing parameters such as FFT size, sampling frequency, and windowing should be investigated experimentally.

4. Experimental Evaluation

Fabricate three to five robots and conduct experiments to evaluate system performance. Possible experiments include:

- single robot detection;
- multiple simultaneous robots;
- varying distances;
- different robot orientations;
- indoor environmental noise;
- interference between neighboring frequencies;
- repeatability over multiple trials.

Performance metrics should include detection accuracy, false detections, processing latency, and computational utilization.

5. Optional Mobile Platform

If sufficient progress is achieved, integrate:

- two DC gear motors with encoders;
- motor drivers;
- differential-drive odometry;
- infrared for obstacle detection.

This extension will enable future research in distributed swarm behaviors.

Composition of Team:

1-2 Electrical (ELE) Engineers & 0-1 Computer (CPE) Engineers.

Skills Required:

Electrical Engineering Skills Required:

- PCB design
- Power electronics and battery management
- Embedded programming in C/C++

Computer Engineering Skills Required:

- Embedded programming in C/C++
- Real-time embedded systems
- Hardware/software integration

Experience with robotics and/or enrollment in **ELE 456 (Mobile Robotics)** is beneficial but not required.

Anticipated Best Outcome's Impact on Company's Business, and Economic Impact

The proposed platform will establish a reusable experimental testbed for swarm robotics research within the Intelligent Control and Robotics (ICRobots) laboratory. Rather than developing custom hardware for each new research project, future undergraduate and graduate students will be able to build upon a common modular platform supporting experiments in robot identification, localization, coordination, and distributed control.

The project also provides a low-cost alternative to more expensive sensing technologies such as cameras, LiDAR, or ultra-wideband localization systems for certain swarm applications. If successful, acoustic neighbor identification could reduce hardware costs while simplifying communication requirements in dense robot swarms.

Beyond its immediate educational value, the platform could support future externally funded research proposals in multi-robot systems, autonomous exploration, and distributed sensing. The reusable hardware architecture may also serve as a foundation for senior design projects, undergraduate research, graduate theses, and demonstrations for outreach activities, increasing the research capabilities and visibility of the ICRobots laboratory.

Broader Implications of the Best Outcome In Rhode Island:

The successful completion of this project would strengthen the University of Rhode Island's educational and research capabilities in robotics and autonomous systems by providing a low-cost, reusable experimental platform for multi-robot research. The platform could support future senior design projects, undergraduate research, graduate theses, and outreach activities aimed at introducing K–12 students to robotics and embedded systems. In the longer term, advances in affordable multi-robot technologies have potential applications in industries relevant to Rhode Island, including marine robotics, environmental monitoring, infrastructure inspection, and autonomous logistics. Developing expertise in embedded sensing, robotics, and distributed autonomous systems also contributes to preparing a skilled engineering workforce capable of supporting the state's growing technology sector.

Appendix A: AI Use Policy – RoboSwarm: An Acoustic Neighbor Identification Platform for Swarm Robotics

Allowed

- Students may use AI tools for:
- ☒ brainstorming support
- ☒ concept development
- ☐ literature and publicly available documentation review
- ☒ software development
- ☒ debugging
- ☒ data analysis
- ☒ test development
- ☒ non-proprietary paragraph editing
- ☐ non-proprietary single-slide formatting
- ☒ preparation of project deliverables
- ☒ note taking or transcription of meetings
- ☐ Others: ______________________________

Not Allowed

- Using AI in violation of university policies, applicable laws, or course-specific rules identified by the capstone instruction team and project-specific rules identified by the technical directors.
- Entering proprietary, confidential, personally identifiable, security-sensitive, or otherwise restricted information into an AI system without authorization.
- Submitting AI-assisted work without understanding, reviewing, verifying, and appropriately disclosing its use.
- Submitting entire documents or presentations to an AI system for editing or formatting.
- Any unchecked items from the allowed list above.

Requirements

- If any use is allowed, AI tools may only be used to enhance, but not replace, students' technical reasoning, engineering judgment, and understanding. Students must be able to explain, justify, and defend all submitted designs, code, analyses, test results, documentation, and conclusions.

- During the first two weeks of the project, the student team shall work with the Technical Directors to:
    - Identify any proprietary or confidential information that may be involved in the project.
    - Determine what information may or may not be shared with AI systems.
    - Identify the AI tools, models, accounts, and configurations approved for project use.
    - Document any project-specific restrictions or approval requirements.
- Students shall transparently document the uses of AI using the URI CYPHER AI Usage Marking guidelines (https://web.uri.edu/cypher/ai-marking/). A workshop is planned for September to familiarize students with these guidelines.
- Students retain full professional responsibility for all design decisions, analyses, implementations, testing, documentation, presentations, and final deliverables, regardless of whether AI tools contributed to the work.