Development of an Audio Source Localization Robot using TDOA Estimation

Interim Project Presentation

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Problem Statement and Motivation

- Current sound localization methods often require complex sensor arrays or high computational resources.
- Need for accurately estimating the direction of a sound source in real-time using minimal hardware (stereo microphones).
- Importance in enabling robots to interact intelligently with their environment based on acoustic cues.
- Practical applications: Search and rescue robots locating people by sound, human-robot interaction using voice, surveillance and anomaly detection.

Project Objectives

- Implement real-time audio signal acquisition using a stereo microphone setup.
- Apply DSP techniques to estimate the direction of a sound source using TDOA.
- Control a robotic platform to move toward or towards the detected sound source.
- Demonstrate real-time embedded audio processing and robot motion coordination.
- Expected Outcomes: Enhances autonomous system capabilities by integrating real-time DSP-based sound localization with robotic motion control.

Methodology / System Architecture

- The robot uses two or more microphones to detect the direction of incoming sound by analyzing the time delay between signals received.
- The raw audio is filtered using FIR bandpass filters to isolate relevant frequencies (e.g., human voice).
- Using cross-correlation or GCC-PHAT, the TDOA is calculated and used to determine the angle of arrival.
- Based on this angle, the robot moves or turns toward the sound source.
- Languages: C++, Python, Platforms: Arduino IDE

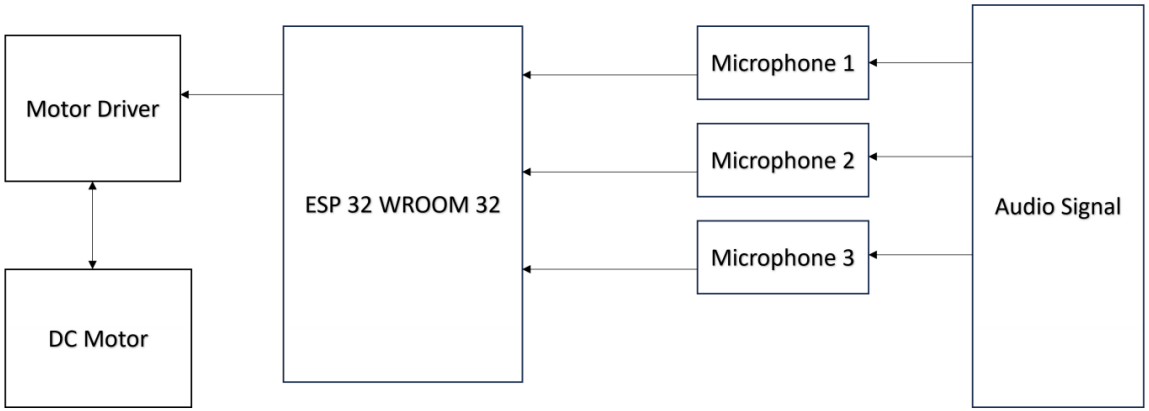
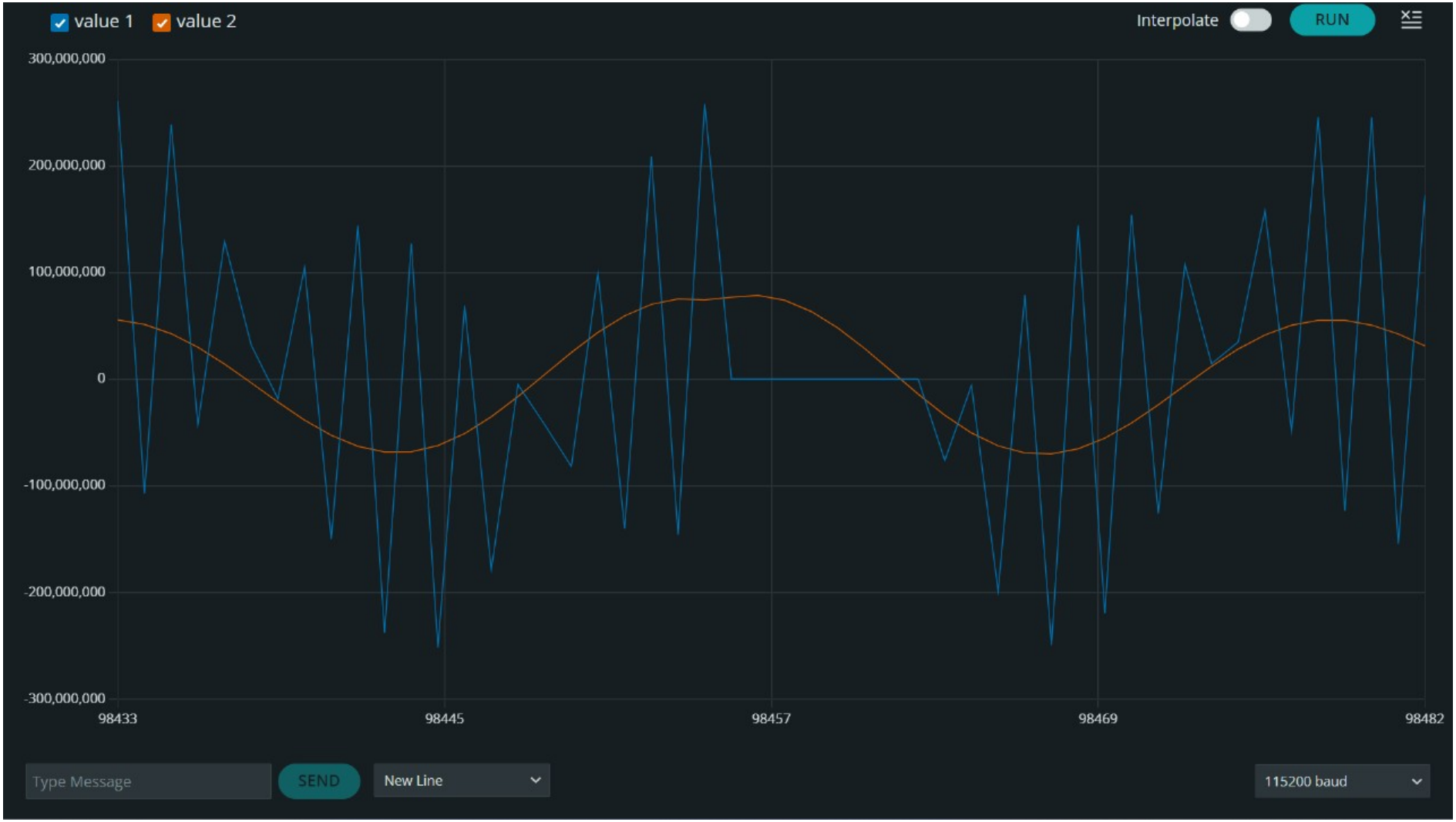


Figure: System Architecture / Flow Diagram

Current Progress

- Project Timeline:
  - Week 1–2: Hardware setup with ESP32 and INMP441 digital microphone,
  - Week 3-4: Audio signal acquisition and real-time plotting using Arduino IDE, Implementation of FIR filtering for captured signals.
  - Week 5-6: Integration with DSP algorithms for TDOA estimation and further processing.
  - Week 7-8: Robotic platform control based on estimated sound source direction.
- Work Completed Till Now:
  - Successfully captured voice signals using INMP441.
  - Plotted real-time audio signals on Arduino IDE Serial Plotter.
  - Applied FIR filtering to smooth the acquired signal.
- Challenges Overcome:
  - RAM limitation when increasing FFT/FIR sample size beyond 128 (tried 256, 512, 1024 — caused memory overflow).
  - Achieved smooth signal acquisition by optimizing for 128-sample processing.



- Blue: Captured signal
- Orange: FIR Filtered signal

Future Plan and Challenges

- Pending and Future Tasks:
  - Integration with DSP algorithms for TDOA estimation and further processing.
  - Robotic platform control based on estimated sound source direction.
- Anticipated risks or challenges: Trying to increase the sample size to 1024 samples, and overcome RAM limitations.

References

1. For referring to FFT based programming using FFT Library in Arduino IDE- https://github.com/kosme/arduinoFFT/wiki
2. I2S Protocol basics and ESP32 based integrations- https://dronebotworkshop.com/esp32-i2s/

DEMO