EEE3097S 2023 Project description: Acoustic Triangulation using Time Difference of Arrival and a distributed sensor network.

Background:

Acoustic localization is an important field with applications ranging from robotics to audio signal processing. Acoustic triangulation is a technique used to determine the position of a sound source by measuring the time difference of arrival (TDoA) of sound signals at multiple distributed microphones. This technique has produced great results in multiple fields in the industry with a wide range of projects currently under development like gunshot detection in the city and UAV surveillance. This project focuses on implementing an acoustic triangulation system using TDoA to accurately determine the position of an acoustic transmitter within a defined grid.

Problem Statement:

The objective of this project is to design and implement an acoustic triangulation system using TDoA to accurately locate the position of a sound source within a rectangular grid. The system will utilize four microphone breakout boards and **two** Raspberry Pi microcontrollers to capture and process audio signals, and then calculate the two-dimensional coordinates of the sound source within the grid and display the predicted results through a **graphical user interface**.

Suggested methodology:

1. **Background Research**: Conduct research on sound localization, triangulation algorithms, and calculation of TDoA techniques. Understand the principles behind time delay estimation, microphone arrays, signal processing algorithms, and simulation tools used for sound source localization.
2. **Paper Design**:
    - **Requirement Analysis**: Analyze the project requirements and identify the key objectives, constraints, and performance expectations. Define the desired relevant parameters, these could be accuracy, sampling rate, signal-to-noise ratio, etc.
    - **Development of Specifications**: Translate the requirements into detailed specifications for the acoustic triangulation system. Specify the hardware components, software algorithms, communication protocols, and interfaces required for the system.
    - **Subsystem Breakdown**: Identify the subsystems involved in the acoustic triangulation system, such as microphone array, signal acquisition, time delay estimation, localization algorithm, user interface etc. Define the interactions between these subsystems and outline their functionalities.
    - **Inter and Intra Subsystem Interactions**: Describe the interactions and data flow between the subsystems. Identify the dependencies and communication interfaces required for seamless operation.
    - **Detailed Acceptance Test Procedures**: Develop detailed test procedures to validate each subsystem and the integrated system. Define the test scenarios, expected results, and acceptance criteria. Include tests for signal acquisition,

time delay estimation, localization accuracy, noise robustness, and overall system performance.

3. **Simulation Setup**: Simulate the acoustic triangulation system using MATLAB or similar simulation tools. Generate simulated audio signals representing the sound source at different locations within the grid. Incorporate noise and other environmental factors to mimic real-world conditions. Verify the accuracy of the simulation by comparing the estimated sound source positions with the known positions.
4. **System Setup**: Assemble the hardware components by connecting the four microphone breakout boards to the Raspberry Pi microcontroller. Ensure proper power supply and establish communication between the Raspberry Pi and the microphones.
5. **Signal Acquisition and Preprocessing**: Develop code to capture and preprocess audio signals simultaneously from all four microphones using the **two** Raspberry Pi. Implement necessary techniques for synchronization, data acquisition, and noise reduction.
6. **Time Delay Estimation**: Implement signal processing algorithms to estimate the time differences of arrival between the microphones. Calculate the TDoA values for each microphone pair based on cross-correlation, generalized cross-correlation (GCC), or other suitable methods depending on the outcomes of your research. Verify the accuracy of the time delay estimation using simulated data.
7. **Localization Algorithm**: Develop an algorithm to triangulate the 2D coordinates of the sound source within the grid based on the calculated TDoA values. Consider methods such as centroid localization, multilateration, least squares estimation and any other relevant methods arising from your research. Evaluate the accuracy of the algorithm using simulated data and adjust as needed.
8. **Performance Evaluation**: Evaluate the performance of the acoustic triangulation system using simulated data. Assess the accuracy, robustness, and limitations of the system under different scenarios. Analyze and optimize the system's signal processing algorithms for better performance.
9. **Hardware Implementation**: Implement the acoustic triangulation system on the **two** Raspberry Pi using the verified signal processing algorithms. Test the system with real audio signals and evaluate its performance in a practical setting.
10. **Documentation and Demonstration**: Document the entire project, including the design, implementation, challenges faced, simulation results, and hardware performance. Provide comprehensive documentation of the signal processing algorithms used. Prepare a report and a demo summarizing the project's key aspects, simulation results, and hardware implementation.

Note: The suggested methodology includes the rectangular grid design as one approach to triangulating the Cartesian coordinates of the acoustic transmitter. Students can explore alternative methodologies or improvements to the suggested approach to further enhance the system's performance.

Constraints

You are to be provided with the following hardware:

- 2 Raspberry pi zeros: https://www.raspberrypi.com/documentation/computers/raspberry-pi.html
- 4 Adafruit I2S MEMS microphone breakout boards:

- A1 size printed grid

You will not be provided with:

- Audio source – You will be required to make use of the speakers of your smart devices. Below are links to an example smartphone application capable of generating acoustic sounds at specific desired frequencies:
    - Android: https://play.google.com/store/apps/details?id=com.tmsoft.whitenoise.generator.tone&hl=en_US&pli=1
    - IOS: https://apps.apple.com/bs/app/tone-generator-audio-sound-hz/id1206449238

Marks Distribution

Assessment Task	%
Milestone 1 (Paper design)	25
Milestone 2 (1st progress report)	25
Milestone 3 (2nd progress report)	25
Final Report	25
Total	**100**

Bonus Marks(10%): Acoustic Source Tracking

For students seeking an additional challenge and the opportunity to earn bonus marks, the project offers the option of implementing acoustic source tracking capabilities in addition to the basic acoustic triangulation system. Acoustic source tracking involves continuously estimating the position of the sound source as it moves within the grid. This functionality requires real-time processing and advanced signal processing techniques. Implementing source tracking demonstrates a deeper understanding of sound localization and opens avenues for more complex applications.

To incorporate acoustic source tracking into your project, consider the following steps:

1. **Extended Signal Processing**: Enhance the existing signal processing algorithms to enable real-time tracking of the sound source. Explore techniques such as particle filtering, Kalman filtering, or beamforming to estimate the position of the source as it moves.
2. **Dynamic Time Delay Estimation**: Modify the time delay estimation algorithm to adapt to changes in the sound source position. Implement techniques to update the time delay estimates continuously based on the movement of the source.
3. **Source Localization Updates**: Develop an algorithm that updates the estimated position of the sound source using the newly acquired time delay estimates. Incorporate techniques such as motion prediction, velocity estimation, or interpolation to improve the accuracy of the tracking.

4. **Visual Representation**: Enhance the system's user interface to display the real-time position of the sound source within the grid. Use visual cues, such as a moving dot or a heat map, to indicate the source's location dynamically.
5. **Performance Evaluation**: Evaluate the performance of the source tracking functionality by testing the system with simulated or real-time moving sound sources. Assess the accuracy and robustness of the tracking algorithm in different scenarios, including varying source speeds, directions, and grid positions.
6. **Documentation**: Document the implementation of the acoustic source tracking functionality, including the modifications made to the existing system, the algorithms used, and the results obtained. Present the findings, challenges faced, and insights gained during the implementation process.

By incorporating acoustic source tracking into your project, you will demonstrate advanced signal processing skills, algorithm design capabilities, and a deeper understanding of the complexities involved in real-time sound source localization. Successful implementation of acoustic source tracking will earn you bonus marks and further showcase your expertise in the field of acoustic triangulation.