ACOUSTIC SOURCE LOCALIZATION

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OUTLINE

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INTRODUCTION

- **Acoustic source localization** is the process of determining the location or direction of origin of a sound in a given environment
- Implemented using an array of **sensors** or **microphones**
- The goal is to estimate the position or direction of **source origin**

1. K. Rashida, S. Kamal, C. Satheesh Chandran, A. A. Balakrishnan and M. H. Supriya, "Prototype Implementation of Spatial Filtering using Sensor Array," *2019 International Symposium on Ocean Technology (SYMPOL)*

Sensor Characteristics

- Microphone Array Configuration
- Number of Microphones
- Microphone Sensitivity
- Frequency Response
- Directional Characteristics
- Noise Characteristics
- Dynamic Range

1. K. Rashida, S. Kamal, C. Satheesh Chandran, A. A. Balakrishnan and M. H. Supriya, "Prototype Implementation of Spatial Filtering using Sensor Array," *2019 International Symposium on Ocean Technology (SYMPOL)*

APPLICATIONS

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1. Smart Home and IOT Applications

- ➢ By accurately localizing sound sources within the **home environment**
- ➢ These systems can provide personalized experiences, enhance user interaction, and improve the **efficiency** of home automation tasks

4.Jekateryńczuk, G.; Piotrowski, Z. A Survey of Sound Source Localization and Detection Methods and Their Applications. *Sensors* **2024**, *24*, 68.

APPLICATIONS

2. Industrial Inspection and Maintenance

- ➢ For **monitoring** and **maintenance** of machinery and equipment
- ➢ Helps in **detecting** abnormal sounds,vibrations, or leaks in industrial processes
- ➢ Can **identify** potential malfunctions or defects early preventing equipment failures

4.Jekateryńczuk, G.; Piotrowski, Z. A Survey of Sound Source Localization and Detection Methods and Their Applications. *Sensors* **2024**, *24*, 68

APPLICATIONS

3. Military and Defense

- ➢ **Locate** enemy threats, such as gunfire, artillery, or unmanned aerial vehicles (UAVs)
- ➢ Battlefield **surveillance**
- ➢ Target **detection**

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APPLICATIONS

4. Surveillance and Security

- ➢ Detect and **locate** suspicious sounds, such as gunshots, explosions, or unauthorized intrusions
- ➢ Respond quickly to potential **threats** and enhance situational awareness in sensitive areas like airports, military installations, and urban environments

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APPLICATIONS

5. Search and Rescue Operation

- **Locate individuals** in distress, such as lost hikers, earthquake survivors, or victims of natural disasters
- By **detecting** and **pinpointing the source** of distress signals or calls for help

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Techniques used for ASL

1. Conventional Beamforming

ADVANTAGES

- Real time processing
- Robust
- Interpretability

DISADVANTAGES

- Require Prior Information
- Limited in Complex Environment
- Sensitive to Array Geometry

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Techniques used for ASL

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2. AI and ML Techniques

ADVANTAGES

- Adaptability
- Feature Learning
- Flexibility

DISADVANTAGES

- Complexity
- Data Dependency
- Black Box Nature

3. Chung, M.-A.; Chou, H.-C.; Lin, C.-W. Sound Localization Based on Acoustic Source Using Multiple Microphone Array in an Indoor Environment. *Electronics* 2022, *11*, 890.

Literature Survey

REFERENCE	METHODOLOGY	RESULTS	FUTURE WORK
Chung, M.-A.; Chou, H.-C.; Lin, C.-W. Sound Localization Based on Acoustic Source Using Multiple Microphone Array in an Indoor Environment. *Electronics* 2022, *11*, 890.	The **TDOA** is also designed to deal with the problem of **delay in the reception of sound signals** from two microphone arrays by using the **generalized cross-correlation** algorithm to calculate the **TDOA**.	The experimental results prove that the proposed method can detect the sound source and obtain good performance with a position error of about **2.0~2.3 cm** and angle error of about **0.74 degrees**	Localize **moving sound** sources under this framework, i.e., how to localize them accurately considering the **Doppler effect**.

Literature Survey

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REFERENCE	METHODOLOGY	RESULT	FUTURE WORK
Jekateryńczuk, G.; Piotrowski, Z. A Survey of Sound Source Localization and Detection Methods and Their Applications. *Sensors* **2024**, *24*, 68.	The primary objective of this work was to comprehensively delve into the techniques of sound **source detection** and **acoustic localization** elucidating their diverse applications across both **military and civil** domains.	The primary objective of this research is to serve as a valuable resource for selecting the most **suitable approach** within this domain.	**Refinement of Algorithms:** refining existing algorithms to improve their **precision and reliability**. This may involve exploring **new signal processing techniques**, optimization methods, or **machine learning** approaches to enhance the accuracy of sound source detection and localization.

Literature Survey

REFERENCE	METHODOLOGY	RESULTS	FUTURE WORK
Hassan, Farrukh & Mahmood, Ahmad Kamil & Yahya, Norashikin & khan, Zia & Rimsan, Mohamed. (2021). State-of-the-Art Review on the Acoustic Emission Source Localization Techniques. IEEE Access. 9. 10.1109/ACCESS.**2021**.3096930.	Numerous localization techniques, such as **Modal Acoustic Emission, Neural Networks, Beamforming, and Triangulation methods** with or without prior knowledge of wave velocity, have been presented	A **deep learning** circular sensor cluster-based solution has the potential to provide a **low-cost** reliable localization solution for acoustic emission sources	**Acoustic Emission** signals include noise.Sufficient expertise in **signal processing** is required to analyze the excellent quality of recorded AE signals for damage localization **AE** signals may wrongly be interpreted as original signals, resulting in incorrect localization results.

Literature Survey

REFERENCE	METHODOLOGY	RESULTS	FUTURE WORK
Kan, Yue et al. “Passive Acoustic Source Localization at a Low Sampling Rate Based on a Five-Element Cross Microphone Array.” *Sensors (Basel, Switzerland)* 15 **(2015)**: 13326 - 13347.	Accurate acoustic source localization at a **low sampling rate** (less than 10 kHz)	**Absolute error** of the localization results based on the **US-GCC** method with the **interpolation factor 15** is approximately from **1/15 to 1/12**-times that based on the **GCC** method with the same sampling rate.	Possibility is given for applying the **US-GCC** method with an interpolation factor of 15 to a **small portable system,** especially a multitasking **micro-embedded** system

Literature Survey

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REFERENCE	METHODOLOGY	RESULTS	FUTURE WORK
Rascon, Caleb, and Ivan Vladimir Meza Ruiz. “Localization of Sound Sources in Robotics: A Review.” Robotics and Autonomous Systems 96.C (**2017**): 184–210. Web.	The main objective of this review is to thoroughly map the current state of the **Sound source localization (SSL)** field for the reader and provide a starting point to **SSL** in robotics.	Robot audition modules, such as **source separation**, and it enriches **human–robot** interaction by complementing the robot’s perceptual **capabilities**.	There are types of sources other than human speech that can be **localized**, such as dog barks, security alarms, whistles, body movements, stride pacing, etc. These are all dimensions of a fertile landscape in which the **SSL** field can **grow**.

Objectives

- To perform **Acoustic Source Localization** using **Signal Processing** techniques in indoor environment

Scope

- Implement of **Delay and Sum Algorithm** for Acoustic Source Localization
- Implement better **Algorithms** for Acoustic Source Localization
- Improve Acoustic Source Localization using **AI/ML** techniques

Beamforming

- Use of an array of **antennas or transducers** to perform signal processing based on the spatial characteristics of a signal.
- Determine the **location of a source** signal in space
- Characterize the signals from sources, to **distinguish different targets**
- Use the signals captured by the microphone arrays to **automatically obtain the position** and details of the acoustic sources.

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Beamforming Algorithms

1. **Delay and Sum Algorithm**

- Signals are **delayed** and **summed** coming from different microphones
- By adjusting delays we can focus on different directions to enhance signals arriving from **specific directions**

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Beamforming Algorithms

2. Minimum Variance Distortionless Response(MVDR)

- **Purpose:** Focus on a desired sound source while minimizing **background** noise.
- **Method:** Calculates the direction that minimizes overall noise while keeping the desired signal clear.
- **Adaptability:** Adjusts continuously to changes in the environment to maintain clarity.

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Beamforming Algorithms

3. Multiple Signal Classification(MUSIC)

- **Objective:** Identify and locate **multiple** sound sources in a **noisy environment**.
- **Process: Separates** sounds picked up by microphones and analyzes **unique arrival patterns**.
- **Identification:** Matches patterns to **determine** the **direction** and **location** of each sound source

2.Desai, *et al* A Review on Sound Source Localization Systems (July 22, 2021).

Delay and Sum Algorithm

- It consists of an array of sensors in a **particular configuration**
- The outputs from all the sensors are **properly aligned** and added up to estimate the source direction
- **Array configuration** should be decided before implementation

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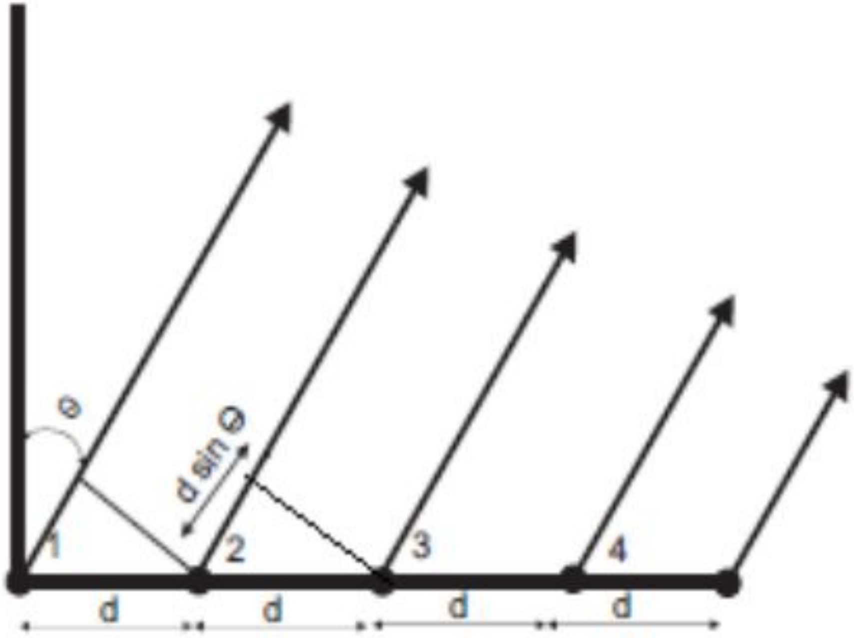
Delay and Sum Algorithm



Uniform linear array configuration

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Delay and Sum Algorithm

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DELAY

$$\tau = \frac{(N-1)\, d \sin\theta}{c}$$

- **N** is the number of microphones
- **c** denotes the speed of sound in air
- The angle of arrival **θ (in degrees)**
- **d (in meters)** between successive elements.

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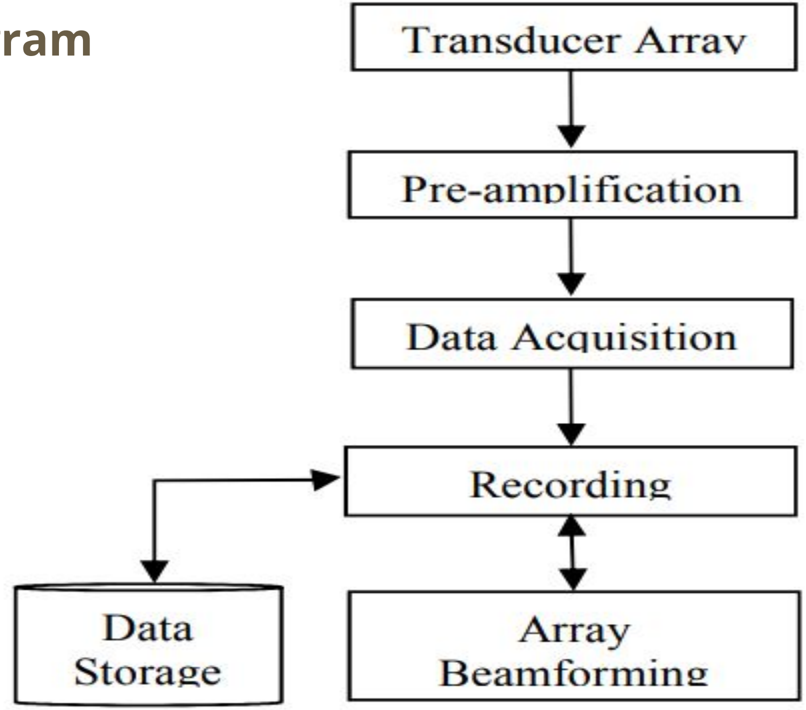
Delay and Sum Algorithm

System Block Diagram



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Delay and Sum Algorithm

System Block Diagram Explanation

- The transducer unit **picks up** the **signal** emanations from both the actual targets as well as the interfering sources
- The pre-processing unit consists of microphone **preamplifier**
- Data acquisition unit performs **analog to digital** conversion
- Digital data is **recorded** on to a storage device
- Array **beamforming** is performed as a post processing operation, in order to get the spatial information

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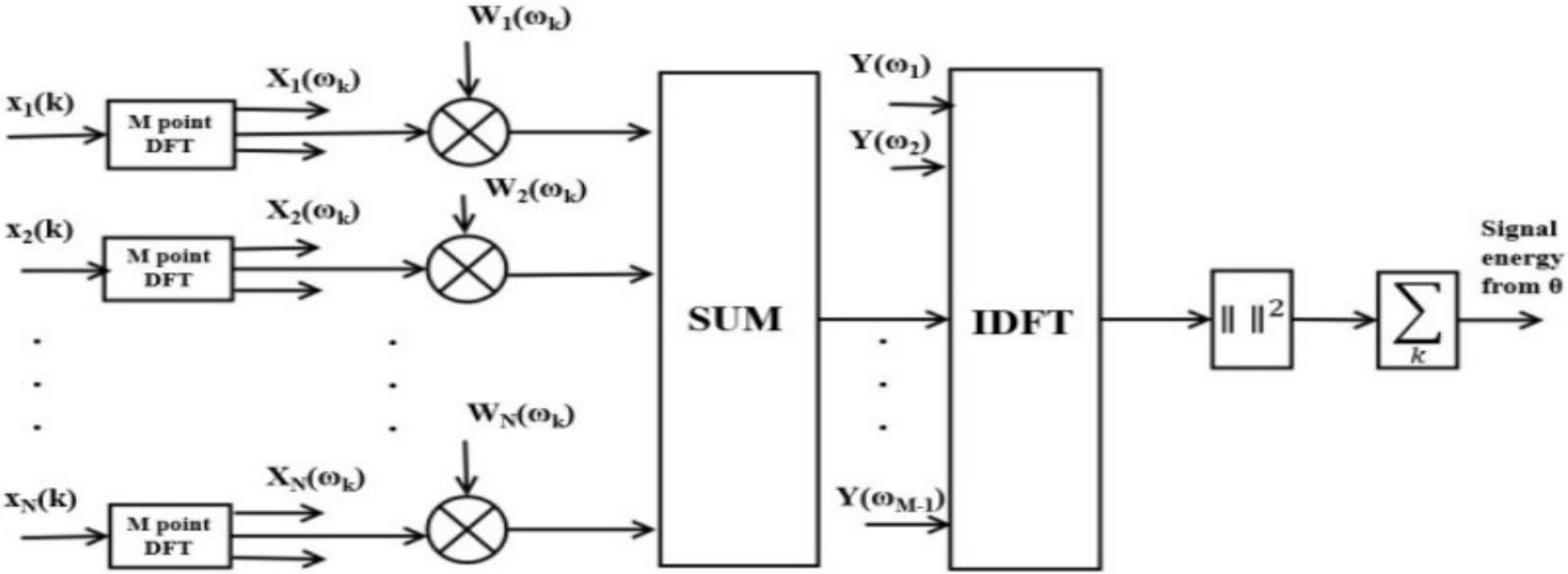
Delay and Sum Algorithm

Frequency domain implementation of wideband beamforming



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Delay and Sum Algorithm

- Let ***s(t)*** be the impinging plane wave signals that are received at the origin of the array coordinate system. Then the signal received at the ***mth*** sensor will be,

$$x_m(t) = s(t - \tau_m)$$

- the output of each sensor is sampled every ***Ts*** seconds where ***Ts = 1/Fs***, where ***Fs*** is the sampling frequency

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Delay and Sum Algorithm

- ***M point DFT*** is taken for each sensor output.
- The mth frequency bin consists of an N×1 complex vector ***Xm***
- where **m = 0 to M – 1**

$$X_m \triangleq [X_0 X_1 \ldots\ldots\ldots\ldots X_{N-1}]$$

- ***Wm*** is the weighting vector corresponding to delay of signal in each sensor

$$Y_m = W_m^H X_m$$

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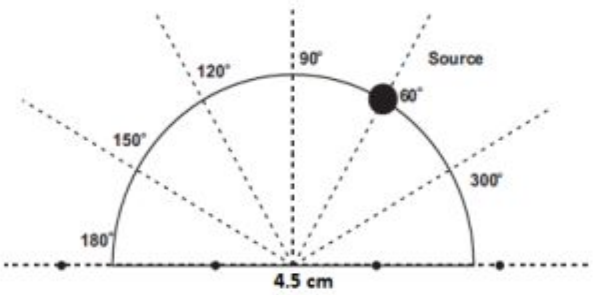
Delay and Sum Algorithm

- Now the sum of all **N values** of each **mth frequency** bin is evaluated to obtain **M** frequency samples.
- Finally, **inverse DFT** is computed to obtain **M output samples** in the time domain
- The output signal energy is calculated for each steering direction from **0 to 180 degree.**



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Inference

- **ASL** can be done using **signal processing** using **Beamforming** techniques and also using **ML**
- In **Beamforming** different **algorithms** are being used which will be chosen according to application
- This approach is **computationally efficient** and can provide accurate localization results, particularly in scenarios with relatively **simple acoustic environments** and a **small number of sources**.
- It requires precise knowledge of the **microphone array geometry** and the **speed of sound** in the environment
- Some other techniques, such as **adaptive beamforming or machine learning-based approaches**, to improve **performance** in more challenging conditions.

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References

[1] K. Rashida, S. Kamal, C. Satheesh Chandran, A. A. Balakrishnan and M. H. Supriya, "Prototype Implementation of Spatial Filtering using Sensor Array," *2019 International Symposium on Ocean Technology (SYMPOL)*, Ernakulam, India, **2019**, pp. 39-46, doi: 10.1109/SYMPOL48207.2019.9005284.

[2] Desai, Dhwani and Mehendale, Ninad, A Review on Sound Source Localization Systems (July 22, **2021**)

[3]Chung, M.-A.; Chou, H.-C.; Lin, C.-W. Sound Localization Based on Acoustic Source Using Multiple Microphone Array in an Indoor Environment. *Electronics* **2022**, *11*, 890.

[4]Jekateryńczuk, G.; Piotrowski, Z. A Survey of Sound Source Localization and Detection Methods and Their Applications. *Sensors* **2024**, *24*, 68.

[5]Hassan, Farrukh & Mahmood, Ahmad Kamil & Yahya, Norashikin & khan, Zia & Rimsan, Mohamed. (2021). State-of-the-Art Review on the Acoustic Emission Source Localization Techniques. IEEE Access. 9. 10.1109/ACCESS.**2021**.3096930.

[6]Kan, Yue et al. "Passive Acoustic Source Localization at a Low Sampling Rate Based on a Five-Element Cross Microphone Array." *Sensors (Basel, Switzerland)* 15 (2015): 13326 - 13347.

[7]Rascon, Caleb, and Ivan Vladimir Meza Ruiz. "Localization of Sound Sources in Robotics: A Review." Robotics and Autonomous Systems 96.C (**2017**): 184–210. Web.

THANK YOU