
# ENGINE-NOISE CANCELLATION TECHNIQUES APPLIED IN VEHICLE-MOUNTED ACOUSTIC ARRAYS WITH BEAMFORMING TECHNIQUES

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This article presents a review and compilation of the techniques that should be used to cancel the noise of the engines of a vehicle where an acoustic array is mounted. A localization system based on microphone arrays mounted close to these high-level noise sources, such as a car engine or the rotors and blades of a drone, introduces strong localization errors that can render the system inoperative. Assuming that the position, the revolutions of the engines and the characteristics of the noise generated by the vehicle engines are known, this article analyzes the current state of the art of the algorithms used for the cancellation of noise sources in the field of beamforming. This article analyzes and classifies the different approaches depending on the application and the objective of the acoustic system. Finally, it presents proposals to improve the current algorithms.

Keywords: Engine-noise, acoustic array, vehicle-mounted, beamforming

## 1. Introduction

Sound sources localization is a big discipline with several different applications that has increase a lot in the last years. The three main sound localization techniques are Beamforming, Holography and Intensity. Holography and Intensity are focused basically on near-field measurements. So their related applications are mainly limited to indoor testing. Beamforming have countless approaches and applications

[1, 2] and it´s easy to find this technology from R+D projects to audio home-appliances and devices [3, 4], even military and defence application [5]. A common system, based on a microphone array and basic beamforming algorithms, can work well in many scenarios, localizing the main noise spots and the secondary ones, and also performing analysis in the frequency domain. But in complex scenarios, with several noise sources surrounding the point of evaluation, localization can be complicated due to the influence of unwanted noise sources on the microphone array acquisition.

As for the use of an acoustic array, considering the possibility that it is not fixed on a tripod on the ground opens up and increases its possible applications. The automotive sector and new autonomous vehicles open the opportunity to use new techniques never used before, like acoustic and ultrasound technologies to localize obstacles, pedestrians or other vehicles while moving. In other hand, the big development on Unmanned Vehicles in the last years provides multiple solutions to carry a complete localization system including data recorder, microphone array, transmitter and power supply. But in their possible workflows, the engines and propellers are very important noise sources, very close to the acquisition sensors. This situation made complicate or impossible some applications, like the ones related with the localization of low level sound emissions.

But engine and propellers acoustic fingerprints can be identified and analysed in order to define their contribution to the signals recorded by the microphone array [6]. The position of the engines are fixed and known in relation with the array position, so it´s possible their correlation. The dependence on load, wind condition and engine revolutions could be also taken into account in this correlation. When these variables are knew, it is possible include them on the localization equation to minimize their affection.

In order to analyse noise cancellation and localization techniques, from a general point of view, a specific application related to industrial noise sources and audio devices has been investigated, beside the ones related to vehicles. So, in this article the authors study and analyse different techniques, algorithms and approaches used in sound localization, providing a compilation of them classified by their application or purpose: short sound events localization; objects, people and vehicles detection; industrial noise sources mapping and sound devices.

## 2. Noise cancellation techniques

Noise cancellation techniques in signal processing can be divided into three main categories [7], as it is shown in Figure 1:

- Homomorphic Signal Processing → Kepstrum: Complex cepstrum, estimation of acoustic path transfer functions [8,9].
- Sensor Array Signal Processing → Beamforming: Sum and subtraction from the signals of each microphone input; Delay and Sum beamforming is one of the more common algorithms [10,11].
- Statistical Signal Processing → ANC: Adaptive Noise Cancelling: Adaptive filtering, in general FIR (Finite Impulse Response), LMS (Least Mean Square) or IIR (Infinite Impulse Response) algorithms [12,13].

This article will be focused on beamforming algorithms based on arrays of acoustic sensors.

## 3. Algorithms classification depending on the application

Depending on the final application, four different categories has been distinguished depending on the localization target:

1- Short sound events: Like gunshots, crash facilities, help yelling or emergency sounds.
2- Objects, people and vehicles detection: Obstacles, vehicles and pedestrian detections from a moving vehicle.
3- Industrial noise sources: Noise mapping on industrial areas or facilities.
4- Sound devices: Voice recognition, echo cancelling and free hand systems.

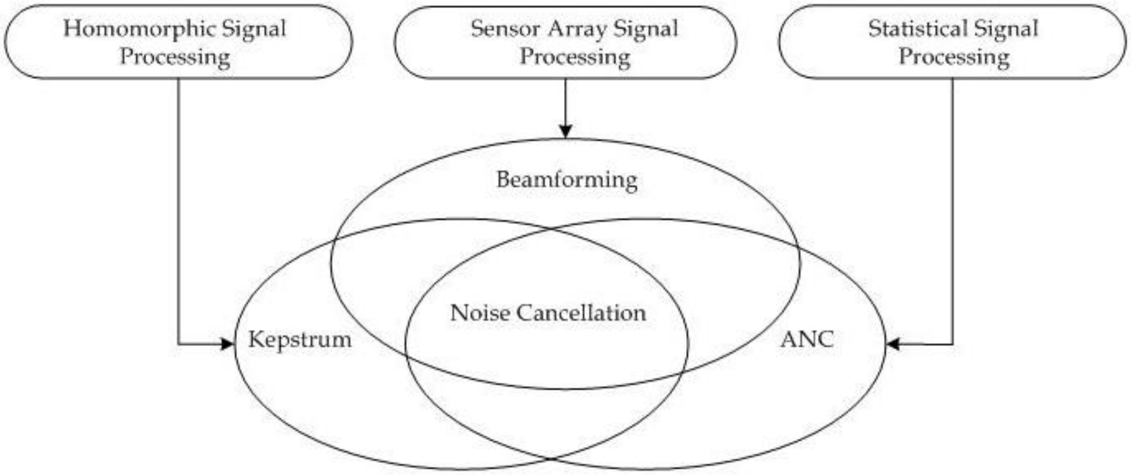


Figure 1: Signal processing techniques and the application of methods for noise cancellation [1]

### 3.1 Applications related to short sound events

Defence and emergency fields are potential scenarios to apply sound localization with several targets. As examples: i) the identification of the position from which a gunshot has come in order to control prohibited hunting areas; ii) in emergency situations where other techniques, like thermography, can`t be used (smoke or mist conditions), the localization of the position where a help yelling or a whistle sound is emitted.

These applications have a common feature: sound emissions to be localized are very short in time, or impulsive. In these cases, it is possible to compare these sounds with the more stable background noise in order to have a clearer acoustic pattern to process or to look for.

Table 1 shows a list of algorithms which are commonly used in these applications.

Table 1: Algorithms classification depending on applications related with short sound events localization.

| Application | Algorithm | Tested / Simulated | Real Time / Post processed | Reference |
|---|---|---|---|---|
| Gunshot Localization | Direction of Arrival (DoA) | Both | PP | Gunshot airborne surveillance with rotary wing UAV-embedded microphone array [14] |
| | Spectral Subtraction | T | RT | A spectral subtraction based algorithm for real-time noise cancellation with application to gunshot… [15] |
| Emissions localization | Spectral + beamforming | T | PP | An acoustic source localization method using a drone-mounted phased microphone array [16] |
| | Multiple Signal Classification | T | RT | Design of UAV-embedded microphone array system for sound source localization in outdoor… [17] |

### 3.2 Applications related to objects, people and vehicles detection

The automotive sector is in the middle of a revolution. In one hand, new propulsion systems have arrived and autonomous driving is a real fact in these days. In addition to the multiple acquisition sensors used on board, obstacles, people and other vehicles can also be located by beamforming, based on emitters and a microphone arrays. One of the great advantages of this technology is the independency on light conditions. Table 2 shows a list of algorithms which are commonly used in these applications.

Table 2: Algorithms classification depending on applications related with objects, people and vehicles detection.

| Application | Algorithm | Tested / Simulated | Real Time / Post processed | Reference |
|---|---|---|---|---|
| Obstacles localization | Direction of Arrival (DoA) | T | RT | Hearing What You Cannot See: Acoustic Vehicle Detection around Corners [18] |
| | Intensity + Kalman filter | T | PP | Acoustic detector of road vehicles based on sound intensity [19] |
| People localization | Wide Band Beamforming + DoA | T | PP | Feasibility of using a mems microphone array for pedestrian detection in an autonomous emergency braking system [20] |
| | Direction of Arrival (DoA) | T | PP | Feasibility of discriminating UAV propellers noise from distress signals to locate people in enclosed environments using MEMS… [21] |
| | Band-pass filter (BPF) | T | PP | Victim Detection Using UAV with On-board Voice Recognition System [22] |
| Drones localization | Hidden Markov Model Classification (HMM) | S | PP | Classification, positioning, and tracking of drones by HMM using acoustic circular microphone array beamforming [23] |
| | Convolutional neural network (CNN) | T | RT | Detection of nearby UAVs using a multi-microphone array on board a UAV [24] |
| | Time-Freq Delay & Sum Beamforming (TDSB+FDSB) | T | PP | Acoustic localization estimation of an Unmanned Aerial Vehicle using microphone array [25] |
| | Time Delay & Sum Beamforming (TDSB) | T | PP | Prototype development of cross-shaped microphone array system for drone localization based on delay-and-sum beamforming in GNSS-denied areas [26] |

### 3.3 Applications related to industrial noise sources localization

Noise levels in industrial areas are controlled under standards, laws and regulation. The first step to reduce noise levels is the localization of where noise sources are located. The advantage on this application is, in most cases, that the noise is stationary. The typical workflow of an industrial facility is constant, from the point of view of noise acquisition. This fact facilitates the identification of the main noise sources and their correlation with frequency. This approach has been used for years with commercial Acoustic Cameras. But sometimes the points of evaluation on the ground are not the best ones or are limited by the terrain and structures; a point of view from the air offer many new possibilities, like taking points from a virtual grid on height, flying over a chimney to know the noise emission depending the directivity, or reaching inaccessible areas.

No special algorithms have been founded applied to perform sound localization in industrial environments from far away distances or from the air, besides Delay and Sum beamforming in time and frequency domain [27].

### 3.4 Applications related to sound devices

The applications, possibilities and customer needs from user sound devices has increase exponentially in the last years. Cell phones with two or three MEMS microphone inside, hands-free systems, voice recognition systems or adaptive speakers systems follow the same target: increase the sound quality experience. Beamforming and noise cancellation are used on this application too. Table 3 shows a list of algorithms which are commonly used in these applications.

Table 3: Algorithms classification depending on applications related with sound devices

| Application | Algorithm | Tested / Simulated | Real Time / Post processed | Reference |
|---|---|---|---|---|
| Audio Quality | Acoustic Echo Cancellation (AEC) + Kalman filtering+ Recursive expectation-maximization | T | PP | An online algorithm for echo cancellation, dereverberation and noise reduction based on a Kalman-EM Method [28] |
| | Robust generalized sidelobe canceller (RGSC) + Instantaneous DoA (IDoA) | T | PP | Robust adaptive beamforming algorithm using instantaneous direction of arrival with enhanced noise suppression capability [29] |
| Mobile Cellular System | Null steering + Min. variance distortion-less response (MVDR) + Min. mean square error (MMSE) | S | P | Performance Analysis of Beamforming Algorithms [30] |
| Hands-free | Wiener, Elko´s and Max. SNIR Beamforming | S | P | Performance analysis of Speech Enhancement methods in Hands-free Communication… [31] |

## 4. Conclusions

In this publication, we have analysed different beamforming algorithms, developed or applied to different applications or purposes: short sound events localization; objects, people and vehicles detection; industrial noise sources mapping and sound devices.

Variables such as background noise, signal-to-noise ratio, noise source level, acoustic fingerprint or the need for real time are some of the important characteristics to develop the technique that best fits the specific application. In some cases, different algorithms, noise cancelation techniques and frequency filtering can be all used together the same application.

In future works, suitable beamforming algorithms will be used in order to minimize engine-noise affection and improve sound localization results from vehicle-mounted acoustic microphone arrays. On top of that, a different idea will be tested, installing acoustic MEMS microphone arrays in no-engine vehicles, exploring the improvement when the localization system is not affected by noise sources nearby.

## Acknowledgements

This research was funded by Ministerio de Ciencia, Innovación y Universidades, grant number RTI2018-095143-B-C22.

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