Calibration System for Multi-sensor Acoustical Systems

Orsola Petrella, Giovanni Cerasuolo, Salvatore Ameduri, Vincenzo Quaranta and Marco Laracca

Abstract In recent years, the multi acoustic sensors systems have had a major development thanks to their versatility in different fields. These systems, also called acoustic antennas, consist of a set of microphones distributed according to linear, planar or three-dimensional geometries. The acoustic signals detected by the microphones are processed in order to define the location of an acoustic source. The acoustic antennas find large applications in different fields. In automotive they are used to highlight the noise propagation path; in the multimedia, these sensors allow localizing a speaker without portable microphones. Also the civil safety and military fields benefit from these systems: gunshots detection in city areas, fire prevention in wooded zones (Blaabjerg et al. in IV International Conference on Forest Fire Research, 2010), soldiers protection from enemy attacks are just some possible applications (ShotSpotter Gunshot Location System® (GLS). http://www.shotspotter.com). Even in the aerospace field, there are interesting applications such as the monitoring of the air traffic zones (ATZ), locating a plane and tracing its trajectory (Quaranta et al. in ESAV 2011-Tyrrhenian International Workshop on Digital Communications-Enhanced Surveillance of Aircraft and Vehicles, 2011 and Petrella et al. in ICSV19, 2012). The identification of the position of the source requires the knowledge of right acoustic locations of the microphones in the array, generally different from the geometric locations, to this scope a suitable calibration procedure. The proposed method was tuned in a simulation environment to predict signal produced by each microphone. An optimization process was adopted to identify layout configuration guaranteeing the right calibration. The proposed solution was experimentally validated on a two-dimensional acoustic antenna.

Keywords Acoustic array · Accuracy · Calibration

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1 Introduction

The development of acoustic arrays of microphones today is of great interest for many applications in different fields and, as a result, under completion in many research projects. The acoustic antenna, through an advanced processing technique called "beamforming" define the position of the source based on the location of the microphones in the antenna and the time delay with which the acoustic signal reaches each microphone with respect to a reference microphone. One of the limitations of these systems is caused by the difference between the geometric and acoustic positions of the microphones due to their position inside the array and the internal features (electronics, inertia of the components). This difference has a dramatic impact in terms of uncertainty in determining the position of the acoustic source. For this reason the acoustic antennas need a dedicated calibration procedure to determine, with appropriate uncertainty, the acoustic position of each microphone used [5, 6]. Comparing with conventional radar, an acoustic system provides some advantages like lower costs, low environmental impact from the point of view of electromagnetic pollution, capacity to detect objects with small radar signature. In military applications, it offers the advantage of being passive, thus non-detectable. In ATZ control applications, and in all those situations where it is required, as well as acoustic source detection, also its spatial localization, a significant aspect is the accuracy that can be achieved in the localization. Logically, the accuracy is connected to acoustic antenna design and realization and it could be improved through a suitable calibration procedure. Various calibration methods and setup are proposed in the literature [7–11] but they do not fully solve the problem of large size acoustic antenna. In this work a methodology and measurement setup is described, tailored for calibration acoustic antennas. The work starts with a brief description of the principles at the basis of the acoustic antennas, to allow a complete understanding of the problems to be solved by the calibration procedure; then a parametric analysis of the proposed methodology was carried out to face its design and realization. Then an optimization procedure was addressed, to spare special size anechoic room, demanded by the large size of the array. Finally, preliminary experimental results on a simplified linear acoustic antenna are reported.

2 Problem Statement

An acoustic antenna is constituted by a set of N microphones allocated in the space, an example is shown in Fig. 1. The microphones allocation could be linear, planar or three dimensional, and with different geometric distributions (random or following specific laws). The acoustic antenna detects the position of the acoustic source by means of a suitable processing of the signals detected by microphones. The signal generated by an acoustic source get to array with a delay that is function of the sound speed and on the distance between each sensor and source. The detection of the

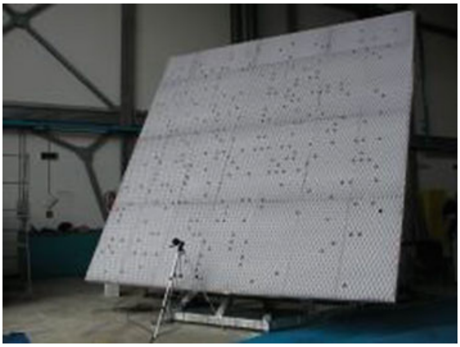


Fig. 1 Microphone array

source location can be done by different way like Acoustic intensimetry, Acoustic Holography, Time Delay of Arrival or Beamforming depending on the number of sources and on the distance. This work focuses on the beamforming technique.

2.1 Acoustic Antenna Calibration

Several critical aspects must be taken into account during the calibration of acoustic antennas. The first one is the right evaluation of microphones positions, strictly related to signal delay detected at each microphone. The delay is in fact a primary parameter due to its greater contribution to the measurement uncertainty in the acoustic source measure. It depends on the electrical and mechanical characteristic of the microphones, on their reception pattern and on the direction the signal coming. Figure 2 shows the effects of these parameters through the distinction between the so called geometric and acoustic locations of the sensors. For the microphone on the left, the source signal crosses the array pattern on a local minimum, differently from what happens for the microphone on the right. This has an impact on the effective time of reception of the signal, thus not depending only by the geometric location of the sensor, but also by its specific array pattern, function of its internal features.

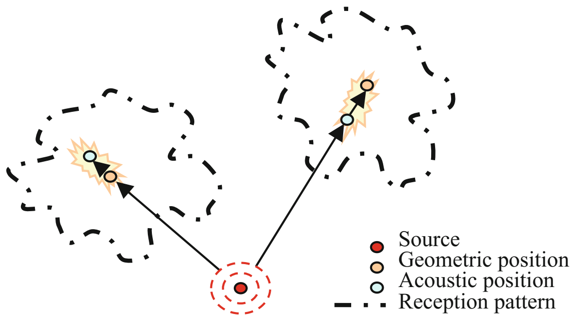


Fig. 2 Difference between acoustic and geometric position

The result of this behavior is an error on the signals delay estimation and, hence, of the locations. Another problem is due to time shift delay.

In fact the triangulation method connotes the cross correlation algorithm based on the assumption that the space shift delay, L, to be estimated is lower than the ratio between the sound speed c and frequency f:

$$L < \frac{c}{f} \tag{1}$$

The signal generated by the *i*th source is received with a certain delay from the reference microphone *r* and the *j*th array microphone. We'll call this delay *Wi,j*, and is estimated through a cross correlation algorithm [8]. After collecting all delays, we can compute the array vector positions $\bar{x}_j^a$ by minimizing the relation

$$\sum_{i}^{N} \left| \left\| \bar{x}_i^s - \bar{x}_j^a \right\| - Wi, j \right| \tag{2}$$

With $\bar{x}_i^s$ the vector position of the *i*th source. If the time delay is larger than the period *T* of the acoustic signal, the cross correlation algorithm gives incorrect results: a time delay of $T + \phi$ is erroneously computed as ϕ, this is due to the periodic nature of evaluated signal [12, 13].

In addition, the arrays considered in this work are also too big and integrated with many microphones; as a consequence, the satisfaction of condition (1) must be carefully verified with respect the anechoic room available space (15 × 20 × 15 m) and operational frequency bandwidth of the array (1–2 kHz).

2.2 Experiment Setup

To solve the above problems, a dedicated strategy was developed. The first necessity is to identify geometric positions that emphasize the array performance. Due to the high number of parameters involved (number and positions of the sources, number and positions of reference microphones) a heuristic strategy based on genetic logic was adopted [14]. The geometric positions were used in the numeric model to obtain the standard deviation and then the acoustic positions. The experimental setup shown in Fig. 3. It is made-up by the acoustic array under calibration, a source array generating the calibration acoustic signals and a reference microphone. A Personal Computer (PC) manages both the generation of the source signals through a signal generator and a power amplifier, and the acquisition of the signals received by the acoustic antenna and the reference microphone. Figure 4 in illustrates a block diagram adopted for the calibration procedure.

Sliding from microphones and sources positions measured through a laser sensor, the pressure signal, p, received by each microphone is estimated as a solution of the spherical wave Eq. (3).

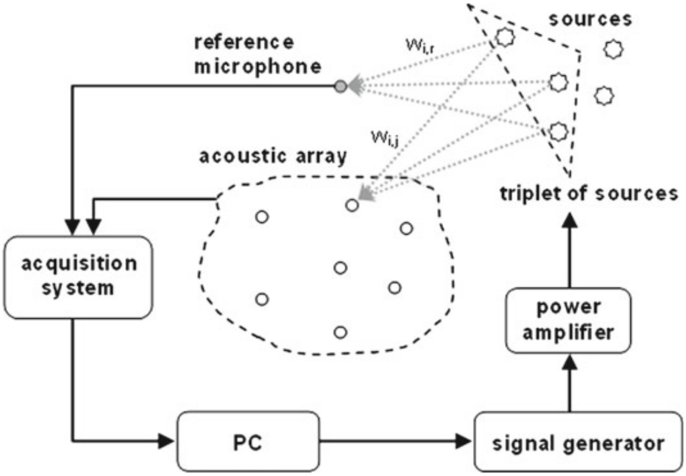
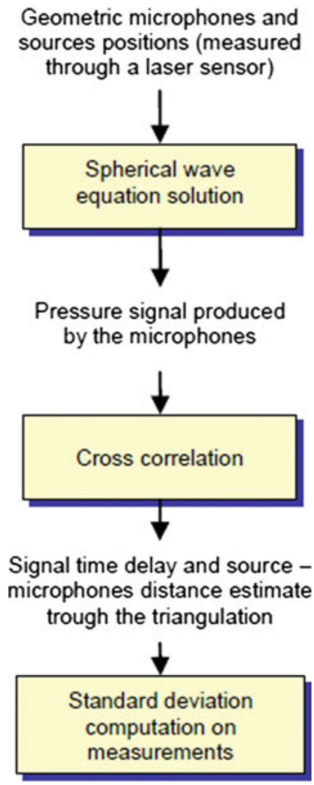


Fig. 3 Experiment setup

Fig. 4 Calibration strategy



$$p\left(\overline{x_j^a}, t\right) = \frac{1}{4\pi c} \int_0^t \iiint \frac{1}{\rho} \delta[\rho - c(t - t_0)] \delta(\overline{x_0} - \overline{x_j^s}) \sin(\omega t_0) d^3 x_0 dt_0 \quad (3)$$

Being ρ the distance between the jth microphone and the position $\overline{x_0}$ of the distributed source element, t the current time, t_0 the time at which the signal is produced, ω the angular frequency and δ the Dirac function. As showed in Fig. 4, moving from an initial approximated position of the array sensors (geometric locations), the acoustical pressure is calculated with wave equation solution; the cross-correlation algorithm is used to estimate the delay between the signals of each array microphone and the reference one. By applying the triangulation algorithm onto the signals produced by all source triplets, it is possible to have an estimate of the location of each microphone. Finally, calculating the standard deviation of the space shift delay on all measurements achieved by all the triplets per each microphone, an estimate of the uncertainty can be obtained.

3 Experiment Result

To validate the methodology, a number of experimental tests were carried out. The experiment setup reported in Fig. 3 was developed considering an Agilent 33220A signal generator connected to a power amplifier 2716 Bruel & Kieran, an LMS International SCADAS SC 310 data acquisition system, an Omnisource 4295 Bruel & kier acoustic source.

The previously described calibration method had already been tested for linear arrays [6], and it had already been established that the source localization improved considerably by using the acoustic positions as input of the realized numerical model (Figs. 5 and 6).

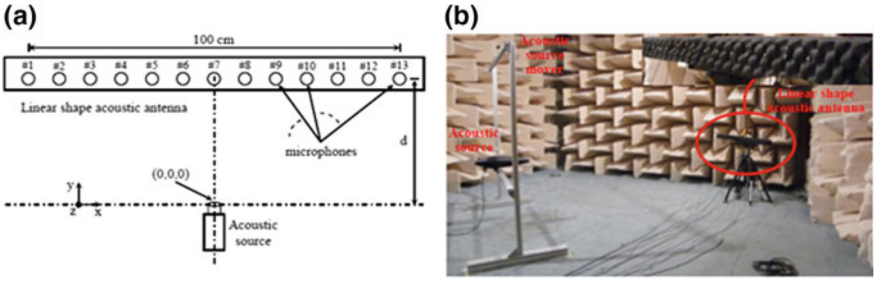


Fig. 5 Schematic (**a**) and picture (**b**) of experiment setup for linear array

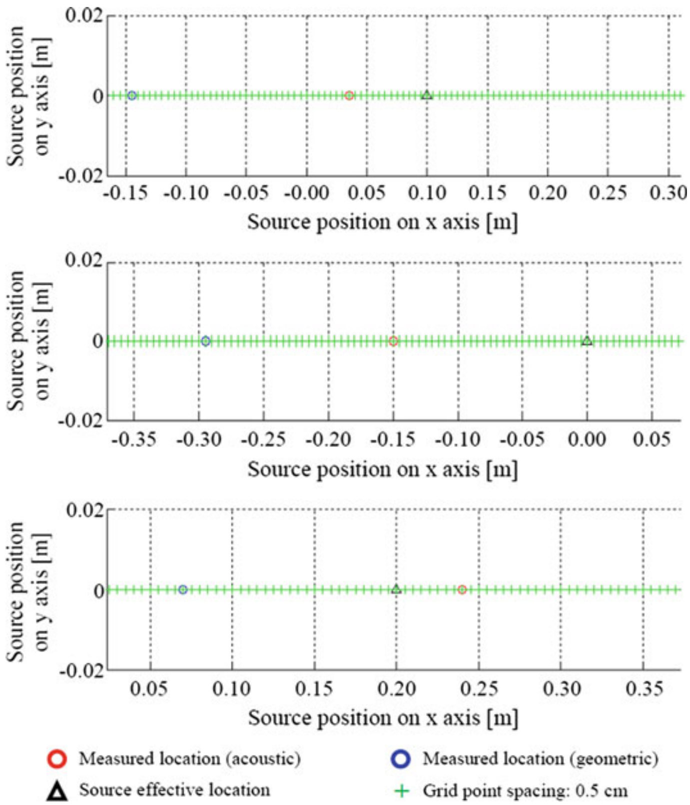


Fig. 6 Comparison between source location measured from both geometric and acoustic microphone positions and the effective source location

At present work a square shape acoustic antenna (two-dimensional array) was used as device under calibration (Fig. 7a). It was constituted by 30 microphones, MPA466 ¼" by BSWA TECH, equally distributed on a linear shape of 1 m length.

The two-dimensional array consists of a wood panel of 1.20 × 1.20 m supported by a wood scaffolding. The two-dimensional array after the realization of the holes for the microphones was covered of sound-absorbing material. All the microphones (Fig. 7b) were numbered and connected to the Data Acquisition System.

To carry out the measurements, the sources distribution used is showed in Fig. 8. The geometric positions were used in the numeric model (Fig. 4) for the determination of acoustic positions. The reference microphone is in a central position.

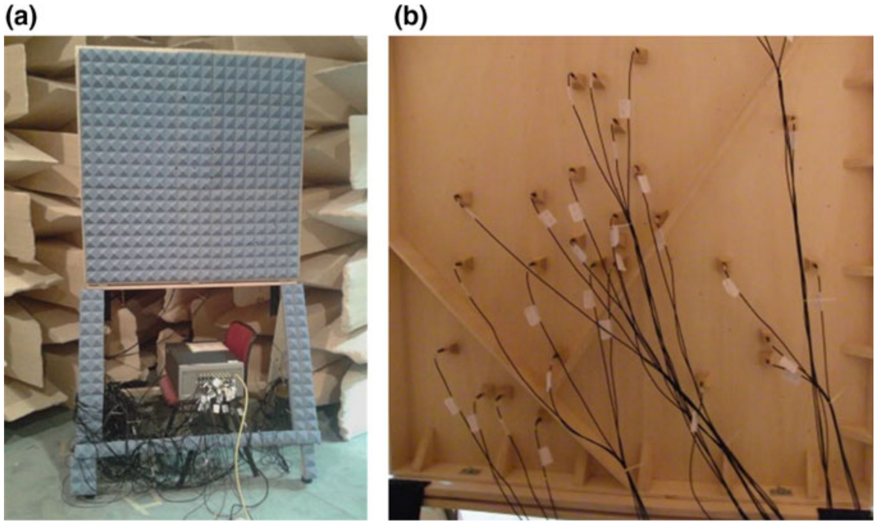


Fig. 7 Front side (**a**) and rear side (**b**) of square shape acoustic array

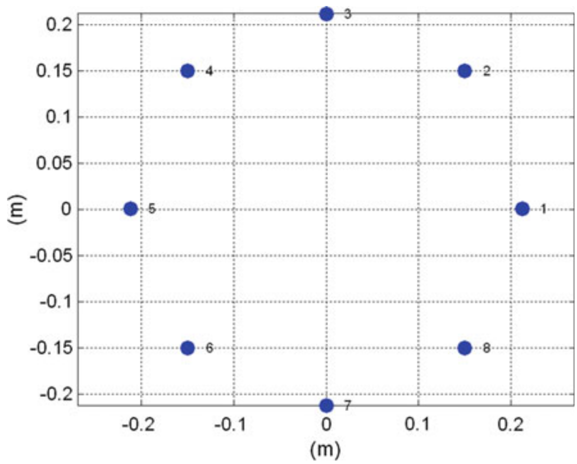


Fig. 8 Sources distribution

The difference between the geometric and acoustic positions obtained with our technique is shown in Fig. 9.

In particular, as we can see from the results of the location of the source, shown in the Figs. 10 and 11 in which the black triangle represents the real position of the source. The blue circle represents the position of the source identified considering the geometric positions of the microphones as input of the localization technique. The

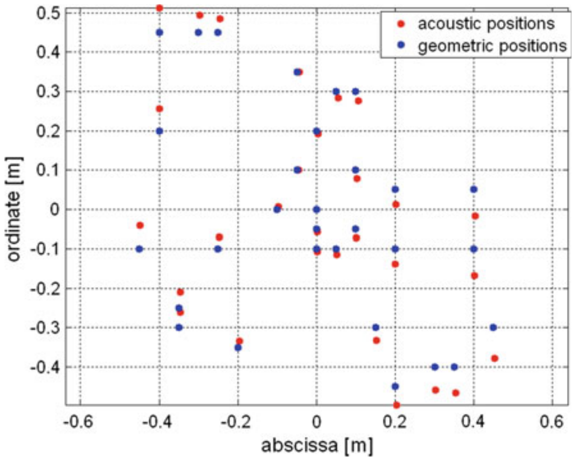


Fig. 9 Geometric (blue) and acoustic positions (red) of the microphones in the two-dimensional array

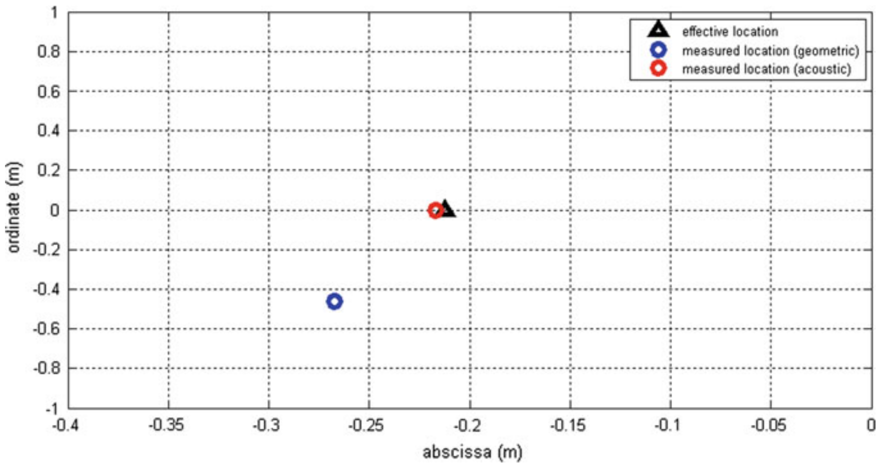


Fig. 10 Localization of the source for the two-dimensional array when the source is positioned at 21 cm from the axis origin

red circle represents the position of the source identified considering the geometric positions of the microphones as input of the localization technique. Using the acoustic positions, the absolute measurement error is reduced by up to 30% compared to that committed with geometric input.

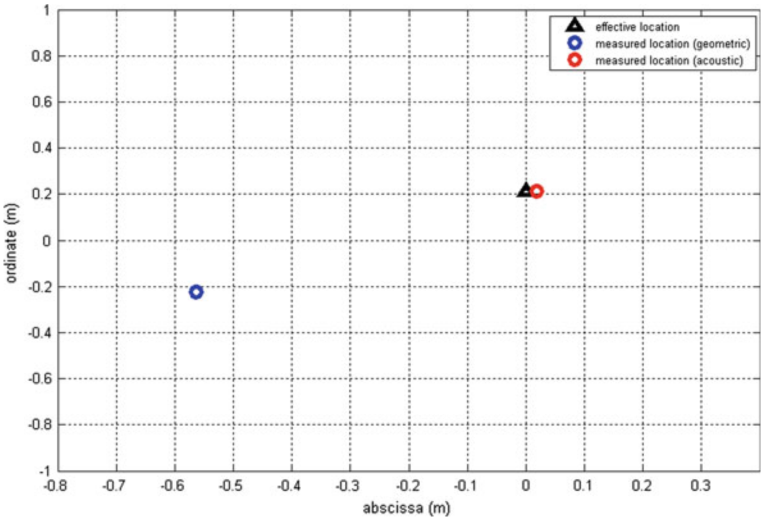


Fig. 11 Localization of the source for the two-dimensional array when the source is positioned in the origin (x = 0, y = 0.2)

4 Conclusions

In this paper, a calibration strategy for arrays of acoustic antennas is shown. The suggested strategy, based on the triangulation method, relies on the comparison of the time delay between array sensor and reference microphone received signals, produced by an assured sum of sources. The accuracy depends on some parameters, like sampling frequency, number of sources, distribution and the distance. A dedicated model was developed, capable of forecasting the pressure signal versus time at each sensor. Two measurement set up were correctly have been made to validate the aforementioned model. The first with a linear array, the second with a square array. An experimental campaign made with both array has confirmed the validity of the method, improving the accuracy and the acoustic source localization after the calibration. In fact, using the acoustic positions instead of the geometric ones, the measurement error decreases by 30% compared to the use of the latter. Additional steps will be focused on testing the whole calibration procedure on large size antennas and on the formulation of the calibration uncertainty.

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