Noise sources investigation by beamforming method

Andrea Cerniglia
Mariagiovanna Lenti

Acoustical beamfoming technique is a new powerful noise source investigation method, which can helps to understand the noise environment, by fast generation of acoustic images (acoustic maps superimposed to pictures or video, even in real-time mode). This paper describes the principles of the technique, and shows some applications including identification of noise sources and evaluation of noise contribution of each source to the global noise value in complex noise environment, noise path analysis, acoustical source recognizion by directional noise emphasis. Beamforming technique can be successfully applied both in urban and industrial environment, as well as in R&D department of transport vehicle designers, in order to reduce noise emission of airplanes, trains, truck or cars.

Principle of beamforming technique

Thanks to fast and faster PCs, today is quite easy to perform a big amount of calculation in a very short time. Modern personal computers, equipped with improved performance CPUs, can be used to implement beamforming calculation, which is not complicated at least in its basic principle, but requires a lot of calculation. The main idea behind the beamforming technique is to combine the signals coming from several non-directional microphones, in order to obtain a very directional sensor: this is done by introducing some position/frequency/direction dependent delays to the signal coming from michrophones, before summing all the signals together. Figure 1 shows the diagram of a non directional microphone (left) and the diagram of the ideal directional sensor obtained by the beamforming technique (right).

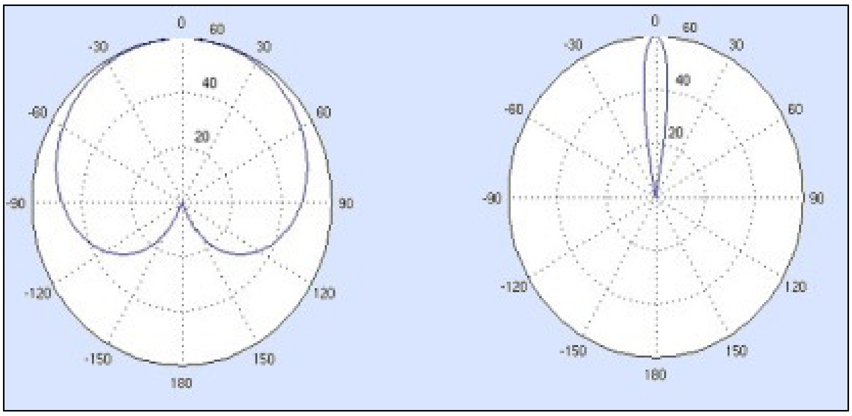
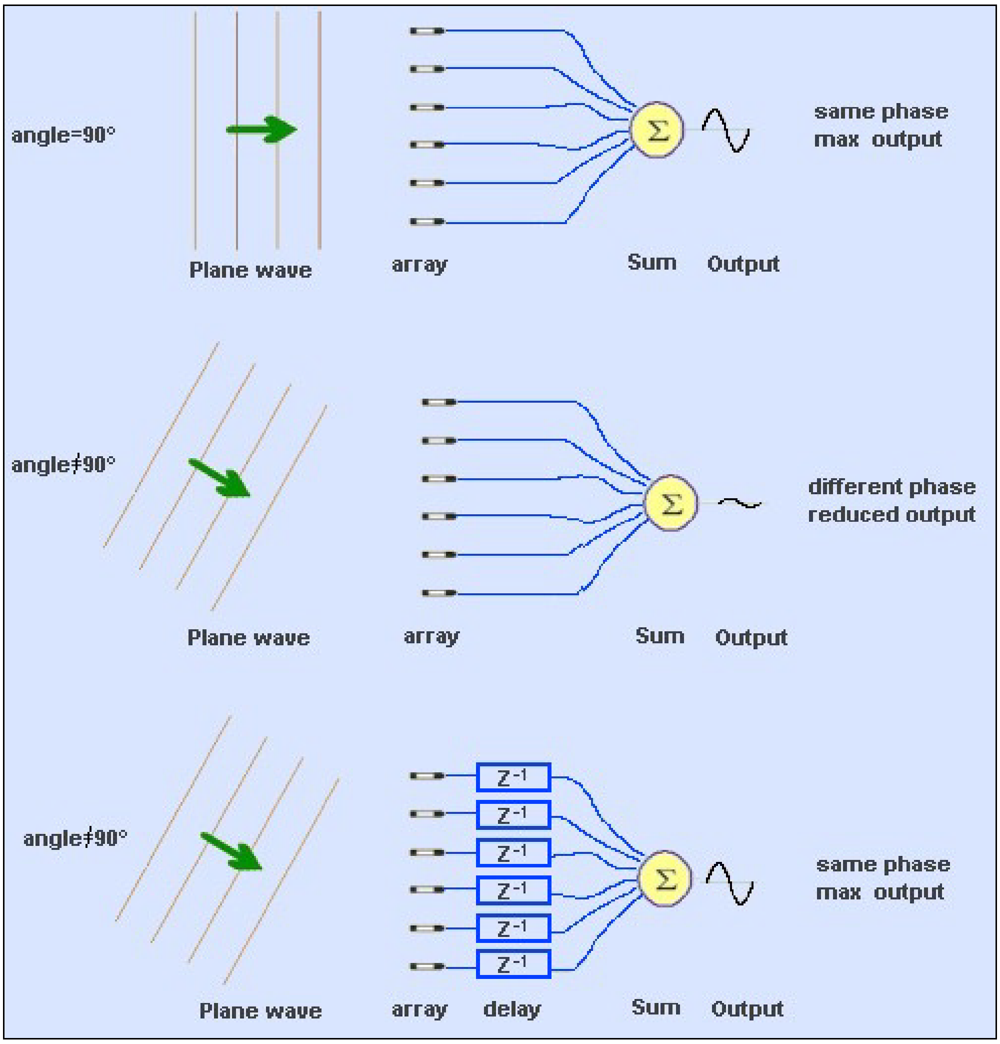


Fig. 1 Diagram of standard microphone (left) and ideal microphone array (right)

For a better understanding of how is possible to obtain this directional sensor by using standard microphones, figure 1 -which shows the simple case of a planar wave that incide a linear array of michrophones- can helps; in the upper part of picture the wave incide perpendicularly the microphone array, while in the mid part a certain angle is assumed, and in the bottom part the same incident angle is compensated by the introduced time delays, according to the position of microphones, frequency of the incoming signal, and direction which should be considered.



Fig, 2: Planar wave on michrophone array, and effect of time delay

In other words, by introducing proper delays, it is possible to obtain a directional sensor for any angle and for any frequency, by using an array of non-directional transducers. As for others acoustic techniques, microphone spacing limits both the lower and the upper frequency of the whole system. While the principle behind beamforming technique is rather simple, the pratical implementation of the system is much more complicated because, as already said, delays are related not just to microphone position, but also to the considered frequency, and they are different for each direction in which the sensor should be electronically pointed. Moreover, a pratical system does not use a single dimension microphone array, but deals with two or three dimension arrays. In a pratical system the above mentioned delays are implemented in digital way by a digital signal process after the AD conversion of the incoming microphone signals. By virtually moving the sensor in any direction ('just' by changing delays), and by interpolate the numerical results obtained for each direction, it is possible to build a map of the selected area and to superimpose it to the picture taken by a camera connected to the system. The sensor used for the measurement descibed in this paper is made with 31 microphones placed on the surface of a sphere of about 25 centimeters of diameter, and with 12 cameras placed on the same surface: the described system permits to obtain a global acoustic view all around the sensor itself. The frequency range of the system used for these measurements, is between 250 Hz and 6300 Hz. Fig. 3 shows the sensor together with the front-end and the portable PC for data analysis. The complete system shown in the picture is very compact and very easy to assemble (no more than ten minutes), and is capable to calculate both post-processed and real-time dynamic acoustic maps.

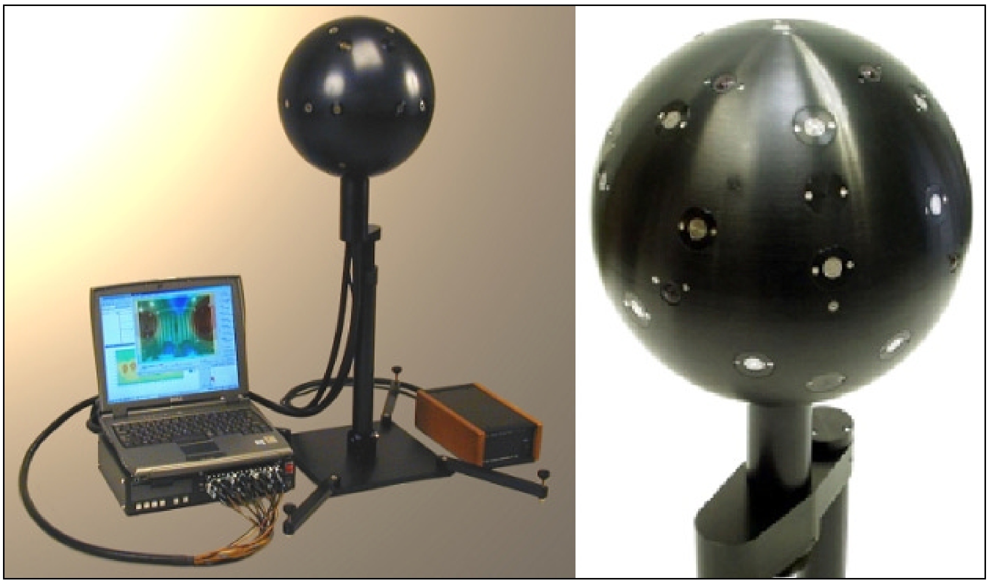


Fig.3: Complete beamforming system (left), closeview of sensor (right)

Applications and measurements examples

Beamforming technique can be very useful in all situation in which is necessary to investigate where the noise is coming from, and expecially in those situation where measurement time is one of the critical aspects of the measurement itself (i.e. measurement on very expensive set-up like airplanes, helicopters, wind tunnels, machines which produce large quantity of goods per time unit, etc…). Figure 4 shows a measurement inside industrial building, performed in order to understand where the noise was coming from: the left part of the picture shows the sensor, while the right noise map shows the noise reflection coming from the ceiling, due to the below production machine.

Fig. 4: Noise map inside industrial building. Sensor (left) and noise map (right)

The time necessary to obtain the acoustic information shown in the above picture, as well as in the other examples in this paper, is in the range of few second, which can move down to the range of millisecond when the system operate in real-time mode (with only one camera instead of twelve, and fixed user definible pre-measurement frequency range instead of after-measurement definable). In real time mode the system can show real-time noise map superimposed to video streaming coming from the selected camera, at the same time of information data storing on the PC's hard disk. In standard mode operation (all cameras, and post-processing user definable frequency band) the system permits to compute animated noise map as post-process, by selecting a user definable window analysis which is automatically moved on the recorded time history; in this case the camera image is fixed while the map is obviously dynamic; the time necessary to obtain the animated noise map in post-process mode, is related with the selected analysis parameters. Frequency analysis can be in narrow band, 1/1 octave band, and 1/3 octave band. From the recorded signal is also possible to extract the beamformed audio signal from a particular direction (just point the mouse and click), in order to make some acoustic recognizion of the received noise from a given direction.

Figure 5 shows an application focused to the determination of the contribution to the external global noise, coming from several sources, in the same indutrial plan. The left part of the picture shows the sensor in place, while the right part shows the noise map from two different cameras, calculated for a certain frequency band. The image shows how, for the selected band, the main contribution is coming from an intake device.

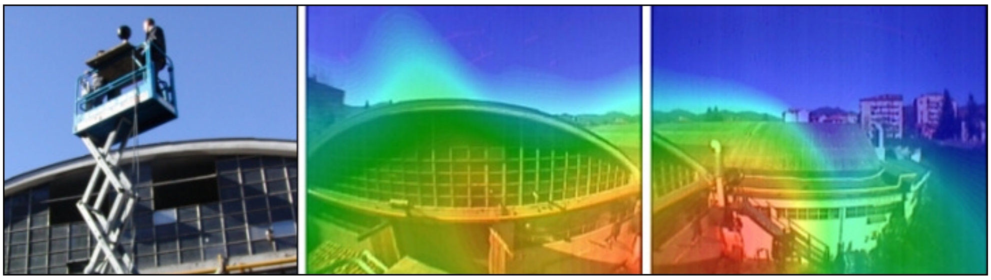


Fig. 5: Noise map outside industrial building. Sensor (left) and noise maps (middle & right)

Figure 6 shows the noise map made on race track, made to investigate which was the most noisy part of the circuit for a certain receiver in some special condition of racing. The numbers on the noise map corresponding to the levels coming from the selected areas.

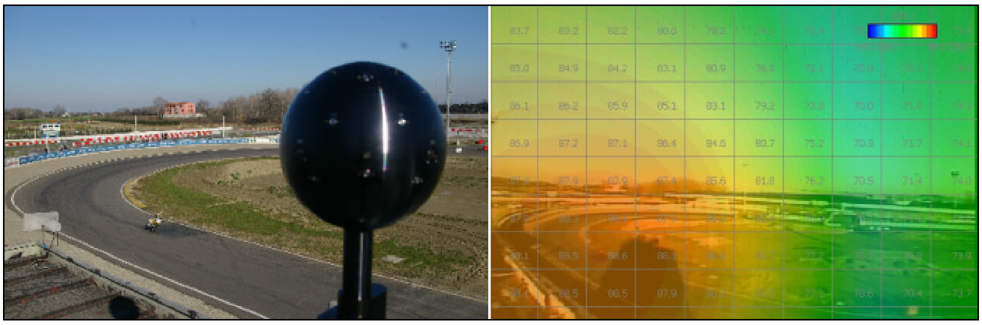


Fig. 6: Noise map in race track circuit. Sensor (left) and noise maps (right)

Figure 7 shows an airplane passage in front of a window. In this map is possible to verify how the map is not centered on the source, because of the the different speed propagtions of light and sound.

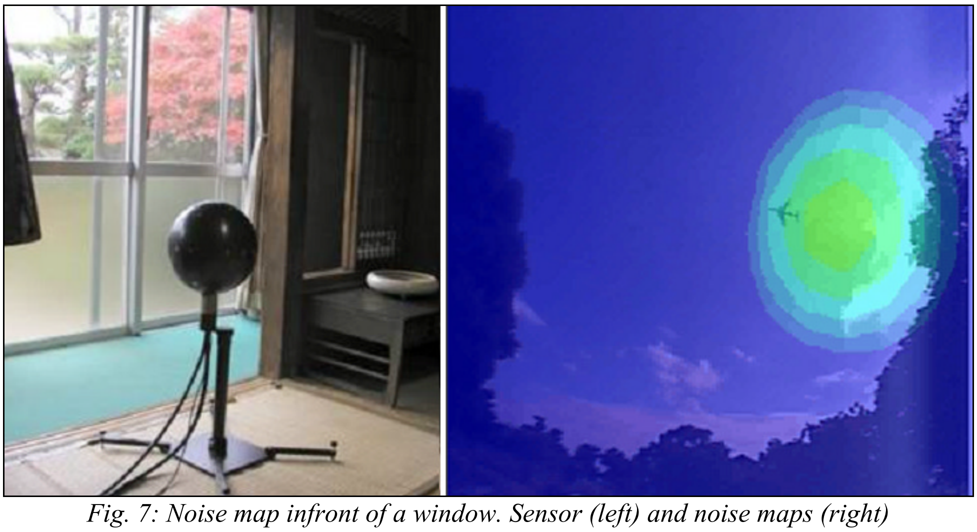


Fig. 7: Noise map infront of a window. Sensor (left) and noise maps (right)

Figure 8 shows the noise map inside an old church during a chorus of almost 800 people. In the noise map is possible to verify that, at the selected time, only the people on the right was singing, while the others was silent. The purpose of the measuremets was to check the sound diffusion inside the church, and to investigate some particular reflections in the church itself.

Fig. 8:Measurement inside an old church. Sensor (left) and noise maps (right)

Figure 9 shows the noise maps of a omnidirectional sound source inside a listening room. On the left, the map of 2000 Hz (1/3 oct) is shown, while on the right it is possible to see the thumbnail of the twelve maps which shows, together with the direct sound, the reflection from the ceiling (top images), and from the floor (bottom images).

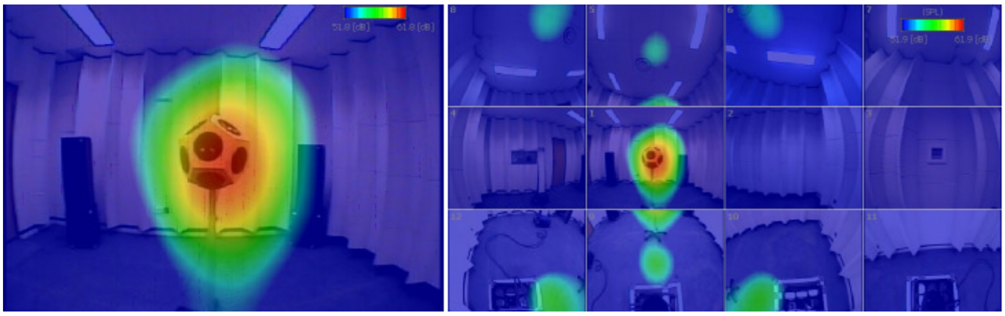


Fig. 9:Measurement on a sound source inside a listening room.2 kHz map (left) ,thumbanail 12 cameras (right)

Figure 10 shows the noise coming from a hydraulic machine. The map put in evidence some possible relation between the noise generated by the motor and the noise emitted at a junction.

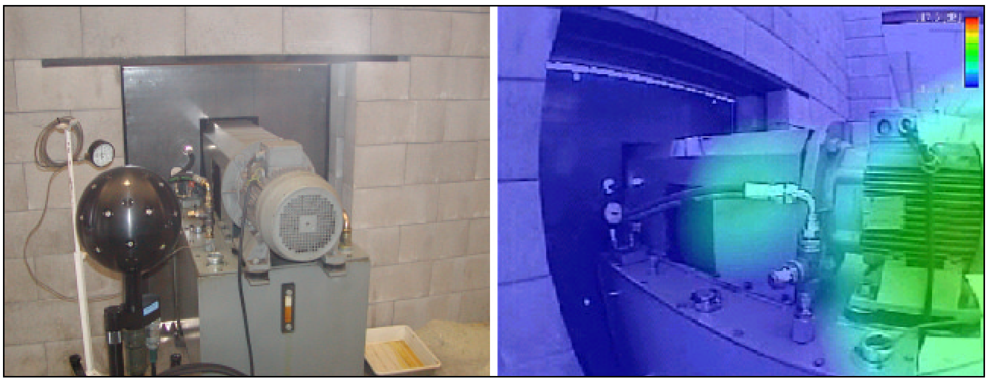


Fig. 10:Measurement inside an old church. Sensor (left) and noise maps (right)

Figure 11 shows the noise coming from a motorbycicle at a certain number of rpm. With the system is possible to separate the noise coming from the different part of vehicles. Typical applications on vehicles includes cabin noise on road, cabin noise on dynamometer bench, cabin noise on wind tunnel, pass by testing.

Fig. 11:Measurement on motorbycicle at given rpm. Sensor (left) and noise maps (right)

Figure 12 shows cabin noise in wind tunnel. The maps –made with a wind speed >140 km/h- shows as, by changing frequency of investigation, different sources may appear. On the Left: noise from external mirror at1.25 kHz; on the right: noise due to some sealing leak at 3.15 kHz.

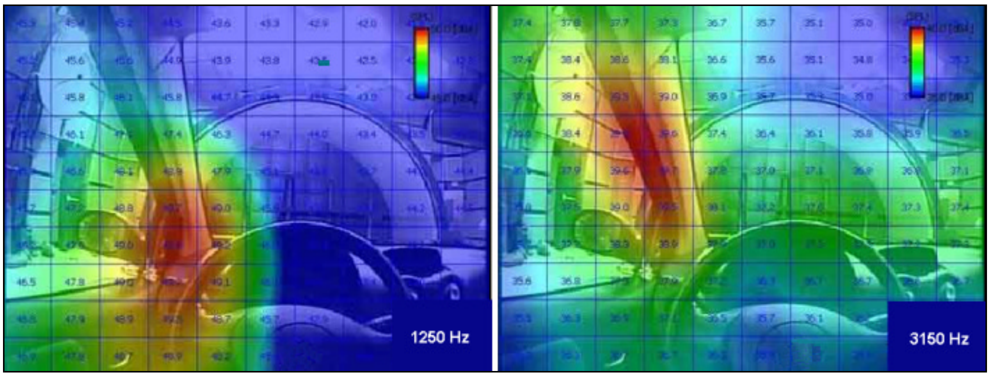


Fig. 12:Cabin noise in wind tunnel.Left external mirror noise; right: sealing leak [courtesy of Pininfarina]

Conclusions

Beamforming technique can be a very powerful tool to investigate complex acoustic situations, including the cases where acoustic phenomena are not stationary. This technique is very effective when the short time for measurement is a must. Beamforming technique should not be confused with acoustic holography technique which, by the implementation of different algorithms, and by using one ore more reference transducer placed on other plane than the measured one, can calculate acoustic field in any plane closer or far from the measured one. In Beamforming technique what is measured is the received noise at a specific position, coming from a specific direction, in the selected frequency band, regardless if the sound is direct sound or reflected one, while in the acoustic holography technique what is measured is the acoustic field itself. The measurements described in this paper, are a prof of the wide application range in which beamforming technique can helps to investigate complex acoustic problems in a reasonably short time.

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