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Axis retrieval of a supersonic source in a reverberant space using time reversal

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ABSTRACT

Localizing the axis of the Mach cone created by the supersonic displacement of a bullet in a reverberant environment is a challenging task, not only because of the high velocity of the moving source, but also because of the multiple wave reflections off of the walls. Although time reversal (TR) techniques allow static acoustic source localization in a reverberant space, they have not been explored yet on non stationary waves caused by supersonic displacements in urban canyons. The acoustic wave produced by a supersonic projectile has a conical wavefront and a N-shaped acoustic pressure signature. In this paper, this acoustic wave is reproduced using a line array of point-like sources (simulations) and loudspeakers (experiments). During the propagation of this conical wave in an urban canyon, the resulting pressure signals are measured using a time reversal array flush mounted into the ground. These acoustic signals allow to automatically retrieve with a high accuracy the location of the Mach cone axis using time reversal techniques. This inverse problem is solved using the maximization of a fourth-order statistical criterion of the backpropagated pressures. This criterion allows to estimate the intersections between the Mach cone axis and several vertical planes in the urban canyon. These estimations are then fitted to a 3D trajectory with a robust three dimensional interpolation technique based on the Random Sample Consensus (RANSAC) algorithm. This method allows to automatically retrieve the axis of the supersonic source with an angular accuracy of less than 0.5° and a misdistance of 0.5 cm for both numerical simulations and experimental measurements.

1. Introduction

Detection of snipers is an important aspect of modern research applied to the protection of soldiers and civilians. Acoustic methods allowing to locate snipers can be applied on the two types of pressure waves implied in the firing of a sniper bullet: the muzzle wave that propagates from the static location of the emitter, and the Mach wave that moves along with the bullet [1]. The shock wave created by the displacement of a supersonic object is described in Whitham's seminal works on the Mach wave [2]. This shock wave is continuously created as long as the projectile is traveling faster than the

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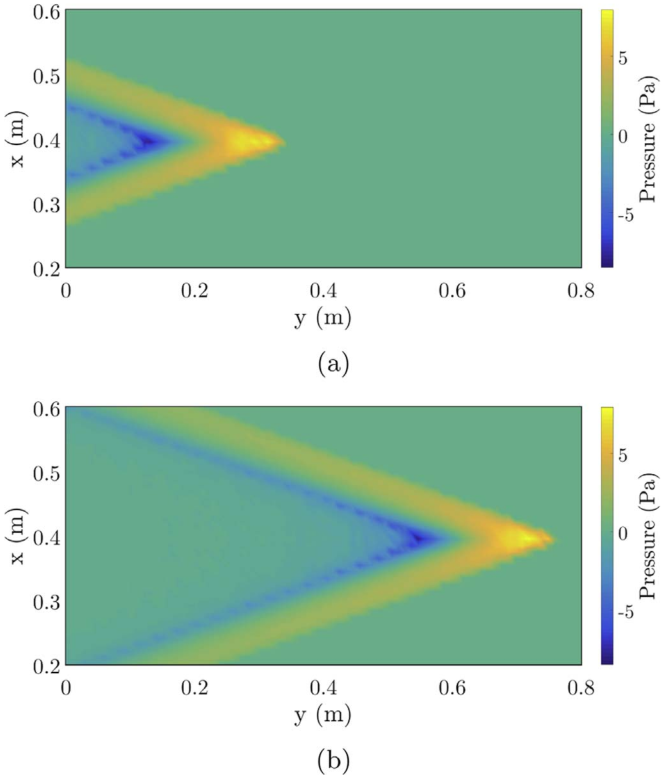

Fig. 1. Numerical synthesis of a Mach cone in free field created using a source array made of 806 monopoles equally spaced by 0.5 cm and located at constant $x=0.4$ m and $z=0.2$ m: 2-D visualization of the conical pressure wave front in plane (z = 21 cm) (a) at $t=2.3073$ ms and (b) at $t=2.7083$ ms.

speed of sound, and this wave trails behind the object, creating a Mach cone (see Fig. 1). As the Mach wave propagates, the acoustic pressure forms an "N" shape with a rapid onset, a ramp to the minimum pressure, and then an abrupt offset (see Fig. 2).

The development of a robust and accurate acoustic method for sniper localization using Mach wave gives rise to challenging difficulties in a reverberant environment. The analysis of gunshot recordings shows that the muzzle wave and its reflections off of boundaries are often mixed with the Mach wave [1,3] and its potential multiple reflections, because of the small propagation delays. The N-shaped acoustic signature of the Mach cone can also be hard to distinguish from the Friedlander shape of the muzzle wave in far-field or in presence of reverberation [4]. Recent investigations on acoustic sniper localization take into account the Mach wave propagation [5,6] using methods based on the estimation of the direction of arrival (DOA) by calculation of the time difference of arrival (TDOA). The TDOA approach leads to good results in anechoic environment [7,8]. However, the presence of reverberation, *e.g.* in an urban area, makes the problem difficult to solve because of the superposition of direct and reverberated data on acoustic recordings [3,9]. The inverse problem of

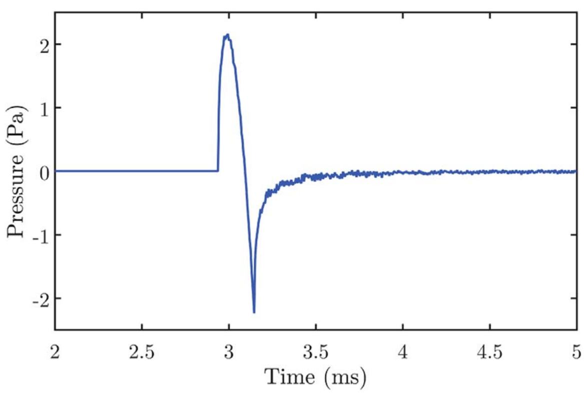

Fig. 2. Numerical synthesis of a Mach cone in free field created using a source array made of 806 monopoles equally spaced by 0.5 cm and located at constant $x=0.4$ m and $z=0.2$ m: time domain visualization of the N-shaped pressure signal obtained at position $x=0.55$ m and $y=0.60$ m.