"HENRI COANDA"
AIR FORCE ACADEMY
ROMANIA

"GENERAL M.R. STEFANIK"
ARMED FORCES ACADEMY
SLOVAK REPUBLIC

INTERNATIONAL CONFERENCE of SCIENTIFIC PAPER
AFASES 2012
Brasov, 24-26 May 2012

DETERMINING THE COORDINATES OF A HOSTILE GUNFIRE BY USING THE SOUND RANGING METHOD

Silviu BĂLUȚĂ*, Gheorghe ANDREI **

* The Military Equipment and Technology Research Agency, Bucharest, Romania
** „Lumina" The University of South-East Europe, Bucharest, Romania

Abstract: *In land warfare, sound ranging is a method of determining the coordinates of a hostile artillery battery using data derived from the sound of its guns (rockets or mortars) firing, and therefore, these known coordinates can be used to direct own artillery fire to the enemy position. This article describes the method of source location based on the relative arrival times of an acoustic signal; there are also presented the advantages and disadvantages of such method, and some aspects regarding the acoustic detection systems' performances.*

Keywords: *acoustic detection, gunshot location system, sound ranging*

1. INTRODUCTION

Sound ranging was one of three methods of locating hostile artillery that rapidly developed in World War I. The others were air reconnaissance (visual and photographic) and flash spotting.

In land warfare, sound ranging is a method of determining the coordinates of a hostile artillery battery using data derived from the sound of its guns firing. Sound ranging using aural and stop-watch methods had emerged before World War I. Stop-watch methods involved spotting a gun firing, measuring the bearing to it and the length of time it took the sound to arrive. Aural methods typically involved a man listening to a pair of microphones a few kilometres apart and measuring the time between the sound arriving at the microphones. This method was quickly discarded as ineffective and replaced by a scientific methods of sound ranging.

The basis of scientific sound ranging is to use pairs of microphones to produce a bearing to the source of the sound. The intersection of these bearings gives the location of the battery. The bearings are derived from the differences in the time of arrival at the microphones.

2. ARTILLERY LOCATION POBLEM

2.1. Principle of Source Location. Acoustic Emission (AE) signals can be broadly divided into two classes: a) burst type emission which is detected as decaying sinusoids and b) continuous emission (resembling white noise). AE source location is based on measurements of the relative arrival times of an AE signal at several transducers and is therefore confined to applications where the sources generate burst type signals. Furthermore, the wave velocity is normally assumed to be uniform throughout the medium.

In the 1-dimensional case, where the source is known to lie somewhere along a straight line between a pair of transducers, a difference in measured arrival times at the transducers uniquely determines the source location.

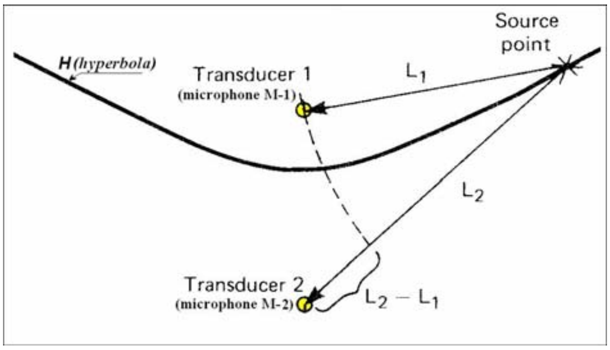

Figure 1. *The AE wave is detected by 2 transducers at different times*

In the 2-dimensional case shown in Fig. 1, where the source is known to lie at a point in a plane, the difference in distance traveled by the wave to a pair of transducers can be calculated from the measured time difference:

$$\tau = v \cdot \Delta t,$$

where τ is the path difference, v is the wave velocity and Δt is the measured time delay. The same path difference is obtained if the source lies at any point along a hyperbola (H), with the transducers at the focuses. Using additional transducers the coordinates of the source can be determined from the intersection of hyperbolas defined by measured time differences at other transducer pairs.

In general, a number of *N* transducers will yield *N-1* time differences and coordinates. Therefore, the minim number of transducers required is two for linear location, three for a plane and four for a volume.

Ambiguous solutions sometimes arise when are used the minimum number of transducers. In order to resolve the ambiguity, additional information must be collected. This can be done by measuring the time delay to an extra transducer and comparing it with the calculated value for the source location.

2.2. Basic equipment setup. A scientific method of sound ranging system requires the following equipment.

- An array of 4 to 6 microphones
- A system capable of measuring the sound wave arrival time differences between the microphones.
- A means of analyzing the time differences to compute the position of the sound source.

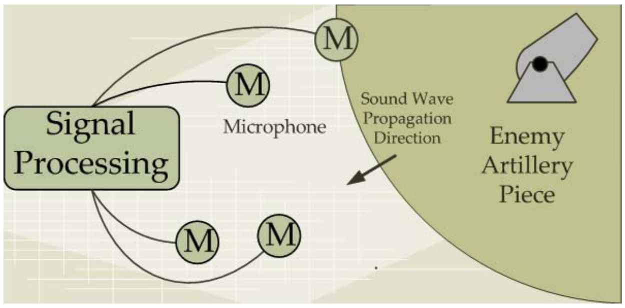

Figure 2. *Basic equipment of a sound ranging system*

The basic method is to use microphones in pairs and measure the difference in the time of arrival of a sound wave at each microphone in the pair (inner microphones are members of two pairs). From this a bearing to the origin of the sound can be found from the point mid-way between the two microphones. The intersection of at least 3 bearing will be the location of the sound source.

Some systems may not allow arbitrary placement of the microphones. For example, they may require the microphones to be placed on a straight line. These constraints would be imposed to simplify the calculation of the artillery position and are not a characteristic of the general approach. The microphones also may be designed to pick up only the sound of the gun firing. There are three types of sounds that can be picked up by the microphone.

- the gun firing (the desired signal)
- the sound of the shell moving through the air
- the impact of the shell

During World War I it was discovered that the gun firing makes a low rumbling sound that is best picked up with a microphone that is sensitive to low frequencies and rejects high frequencies.

2.3. Determining the range to the artillery piece. There are a number of ways to determine the range to the artillery piece.

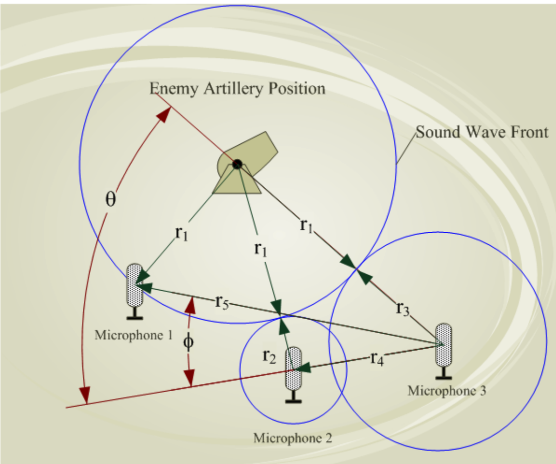

Figure 4. *Example of a sound ranging operation*

One way is to apply the law of cosines twice:

$$\begin{cases} (r_1+r_2)^2 = (r_1+r_3)^2 + r_4^2 - 2\cdot(r_1+r_3)\cdot r_4\cos\theta \\ r_1^2 = (r_1+r_3)^2 + r_5^2 - 2\cdot(r_1+r_3)\cdot r_5\cos(\theta-\phi) \end{cases}$$

This is a nonlinear system of two equations with two unknowns (θ, r_1) which can be solved using numerical methods.

The ranges r_2 and r_3 can be expressed by the relations:

$$\begin{cases} r_2 = v\cdot\tau_2 \\ r_3 = v\cdot\tau_3 \end{cases},$$ where $v \approx 330$ m/s and represents the speed of sound.

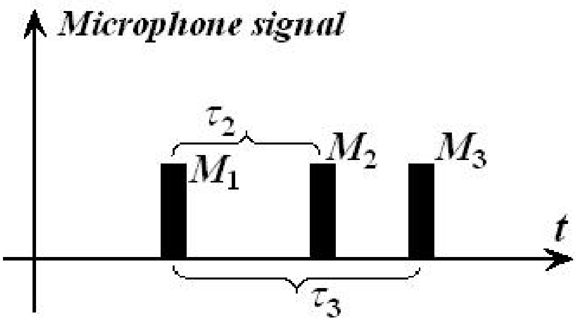

Figure 3. *The signals' delays detected by microphones.*

The two time durations τ_2 and τ_3 represent sound wave front delays assigned to microphones 2 and 3, relative to microphone 1.

3. ADVANTANGES AND DISADVANTAGES OF THE METHOD

2.3. Advantages and disadvantages of the method. Sound ranging has a number of *advantages* over other methods:

- Sound ranging is a passive method, which means that there are no emissions traceable back to the sound ranging equipment. This is different from radar, which emits energy that can be traced back to the transmitter.
- Sound ranging equipment tends to be small. It does not require large antennas nor large amounts of power.

Sound ranging also has a number of *disadvantages* such as:

- the speed of sound varies with temperature. Wind also introduces errors. There are means by which to compensate for these factors.
- at a distance, the sound of a gun is not a sharp crack but more of a rumble (this makes it difficult to accurately measure the exact arrival time of the wavefront at different sensors)
- guns cannot be located until they fire
- artillery is often fired in large numbers, which makes it difficult to determine which wavefront is associated with which artillery piece
- every microphone has to be emplaced and very accurately surveyed to find its coordinates, which takes time
- each microphone has to have a communication channel to the recording apparatus, before effective radio links appeared this meant field cable, which had to be laid and maintained to repair breaks from many causes.

Military forces have found various ways to mitigate these problems, but nonetheless they do create additional work and reduce the accuracy of the method and the speed of its deployment.

4. ASPECTS REGARDING THE SYSTEM ARCHITECTURE

Different system architectures have different capabilities and are used for specific applications. In general there are 2 architectures:

- *stand-alone systems* with local microphone arrays, and
- *distributed sensor arrays* ("wide-area acoustic surveillance").

The former are generally used for immediate detection and alerting of a nearby shooter in the vicinity of the system; such uses are typically used to help protect soldiers, military vehicles and craft, and also to protect small open-space areas (e.g., parking lot, park). The latter are used for protecting large areas such as cities, municipalities, critical infrastructure, transportation hubs, and military operating bases.

Most stand-alone systems have been designed for military use where the goal is to immediately alert human targets so they may take evasive and/or neutralization action. Such systems generally consist of a small array of microphones separated by a precise small distance. Each microphone hears the sounds of gunfire at minute differences in time allowing the system to calculate the range and bearing of the origin of the gunfire relative to the system. Military systems generally rely on both the muzzle blast and projectile shockwave "snap" sounds to validate their classification of gunfire and to calculate the range to the origin.

Distributed sensor arrays have a distinct advantage over stand-alone systems in that they can successfully classify gunfire with and without hearing a projectile "snap" sound, even amid heavy background noise and echoes. Such systems are the accepted norm for urban public safety as they allow law enforcement agencies to hear gunfire discharges across a broad urban landscape of many square miles. In addition to urban cityscapes, the distributed array approach is intended for area protection applications, such as critical infrastructure, transportation hubs, and campuses.

REFERENCES

1. H. J. Rindorf, M.Sc.: "*Acoustic Emission Source Location in Theory and in practice*". Technical Review, No.2 -1981.
2. Harry Bateman: "*Mathematical Theory of Sound Ranging*", Monthly Weather Review. Source : online. Available: http://docs.lib.noaaa.gov/rescue/mwr/046/mwr-046-01-0004.pdf.
3. *Gunfire locator*. Source : online. Available: http://en.wikipedia.org/wiki/Gunfire_locator.
4. J.B. Calvert: "*Ranging*". Source : online. Available: http://www.du.edu/~tech/ranging/ranging.htm. Retrieved 2006-05-15.
5. *State of the Art Shooter Detection*. Source : online. Available: http://www.bbn.com/products_and_services/boomerang/