Acoustic Scoring and Locating System for Rockets, Artillery & Mortars

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Abstract. Acoustic sensors can be used to detect, classify and locate battlefield threats such as mortars, rifles and various vehicles. Sound pressure microphones are commonly used for this purpose, but this article focuses on Acoustic Vector Sensors (AVS's). These sensors consist of three orthogonal particle velocity sensors in combination with a sound pressure microphone. These sensors make it possible to measure the direction-of-arrival of a sound wave instantaneously. The use of multiple sensors leads to very robust source localization and classification. This paper presents a system which consists of multiple Unattended Ground Sensors (UGS's). Applications, with an emphasis on Acoustic Scoring and Locating System for Rockets, Artillery & Mortars (RAM-LOC), are discussed.

Keywords: Battlefield acoustics, CRAM, situational awareness

1 Introduction

Conventional sound pressure microphones measure only scalar value of the sound field, such that measurements at a single point do not yield information on the direction of arrival. Hence, spatially distributed microphone arrays must be used. DOA is calculated based on phase differences between the sound pressure at different locations. This technique has some drawbacks: large system size, limited bandwidth and accuracy loss due to wind and temperature changes.

The acoustic vector sensor (AVS) is a 4 channel sensor which consists of an omnidirectional sound pressure microphone and the three orthogonal acoustic particle velocity sensors, each of which is sensitive in one direction. The ratios between these signals are used to determine the direction of the source. This principle makes it possible to determine the direction of a wide range of sources, from helicopters to hand weapons. Since the sensor is only a few millimeters across, it can be mounted on virtually any platform. This means acoustic vector sensors remove two large disadvantages of the existing acoustic system, making it a uniquely versatile technology. Regarding the benefits of AVS the Acoustic Scoring and Locating System for Rockets, Artillery & Mortars is being under development. The main purpose of this project is to increase situational awareness on the battlefield or on the training range.

This article is built up as follows. Section 2 considers the principles of operation of Microflown sensors. Section 3 considers possible applications. In section 4 Unattended Ground Sensor for boarder control and RAM target practice is described. Section 5 considers source localization on experimental data and in section 6 possible improvements are discussed. Conclusions are drawn in section 7.

2 The Microflown Sensor

Invented in 1994, the Microflown sensor is the world's only true acoustic particle velocity sensor designed to operate in air. As can be seen in figure 1 (left), the sensor consists of two wires which are heated to 200°C above the ambient temperature during its operation. As air flows across the sensor, the upstream wire cools down and gives off some heat to the passing air. Hence, the downstream wire cools down less due to the warmer air. This difference in temperature is measured electrically, making it possible to measure the acoustic particle velocity directly. The heating of the wires requires about 70mW.

From 1994 to 2004, the Microflown sensor was a hot topic in the scientific community, leading to hundreds of scientific papers. From around 2004, the sensor has become widely accepted, primarily in the automotive industry. The technology is currently being used to improve the interior sound quality of the products of almost all major car manufacturers.

Microflown Technologies introduced the first true acoustic vector sensor in 2002 (see figure 1, right). It consists of 3 Microflown sensors and a co-located pressure microphone. The three Microflown elements form the acoustic particle velocity vector. Together with the pressure microphone, the direction of the source can be identified.

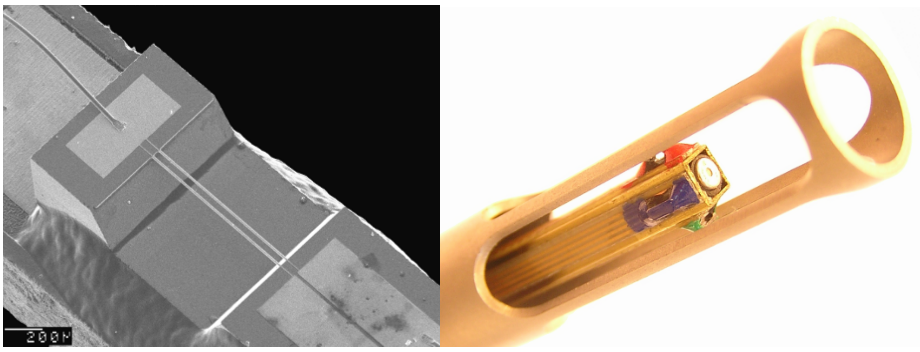

Fig. 1. Left: The Microflown Sensor. Right: An Acoustic Vector Sensor.

3 Applications

This section considers the wide range of defense and security applications of Acoustic Vector Sensors (AVS). Three of the platforms on which the sensors can be placed are discussed: the unattended ground sensor, the unmanned aerial vehicle (UAV) and the ground vehicle. Also, a number of different acoustic signatures are considered.

The main focus of this article lies on the RAM-SCORE system, which is currently under development at Microflown AVISA. This system consists of a network of unattended ground sensors (see figure 2, left) to determine the location of the launches and impacts of Rockets, Artillery and Mortars (RAM). It is used in target practice on military training ranges.

This information is useful for safety officers because it returns up-to-date information about the time and location of shots that are being fired and alert the operator if any rockets or projectiles that land outside the target area. The system also makes it possible give accurate feedback to the practicing infantry or artillery troops. A similar product, called RAM-LOC, is a network of unattended ground sensors for wide area surveillance in counterinsurgency warfare such as in Afghanistan.

Fig. 2. Left: Unattended Ground Sensor. Right: Microflown UAV Demonstrator.

The second platform is the miniature unmanned aerial vehicle (mini UAV) (see figure 2, right). These remote controlled aircrafts, with a wingspan of 1-1.5m are widely used for video surveillance activities by the police and the armed forces. The camera has a narrow field of view, which means the operator is unaware of most things happening around the UAV. The acoustic vector sensor makes it possible to detect and locate any weapon noise, from pistols to mortar fire.

The sensor can also be placed on the ground vehicle platform. Inside an armored vehicle such as the Fennek reconnaissance vehicle (see figure 3), the operators are essentially deaf to external noise. Acoustic Vector Sensors make it possible to alert the camera operator to any threat and, if the operator needs it, rotate the camera towards it. A similar system is being considered for the air target artillery, where threat is not a rifle or mortar, but a helicopter. Although this requires different signal processing, most of the hardware is the same in both applications.

This section considered a number of applications of acoustic vector sensors for defense and security. Three different platforms and various acoustic signatures have been considered. From this point on, this article focuses on the RAM-SCORE system.

Fig. 3. Ground-vehicle-based sensor (technology demonstrator).

4 The Unattended Ground Sensor

The Unattended Ground Sensor (UGS) (see figure 6) is designed to be a self-powered device which records measurement data, classifies events and sends the time and direction of the event to a main station. A network of sensors is used to determine the location of the event based on time differences and directions.

Fig. 4. Left: Unattended Ground Sensor without its windshield. Right: Sensor post.

Each UGS has a diameter of 0.33m (13'') and a height of 0.25m (10''). It contains a computer running Windows, a pre-amplifier, an AD converter and a GPS unit. A 12V/62Ah battery is used to power the system. The 686MHz band is used to transfer data at distances of 10km and more.

To determine the location of the events, the location and orientation of the sensors must be known accurately. For this purpose, the sensors are placed on posts (see figure 4, right). The location of these posts has been measured up to 1m and the orientation is known up to ½ degree.

5 Source Localization

The location of the launches and impacts is determined at the main station. The time and direction of the events is received from all of the sensors and brought together to identify a source location. The details of the source localization algorithm are not discussed because of company confidentiality. As becomes clear in this section, both time differences and directions are used.

Experimental results are collected during military practice shootout at the ASK shooting range (Artillerie SchietKamp). 81mm mortars are launched from known locations and the sensors are placed at 2, 2.5 and 5km from it. The localization results are depicted in figure 5 (left). The colored lines depict the direction of the sound wave, as measured by the sensor. Each blue curve indicates the set of possible launch locations, based on the time difference of one pair of sensors. The intersection of two or more of these curves is the launch position, determined from the time differences. The accuracy can be improved by combining the time differences and the directions. By zooming in to the picture (see figure 5, right), it can be seen that the error is less than 50 meters.

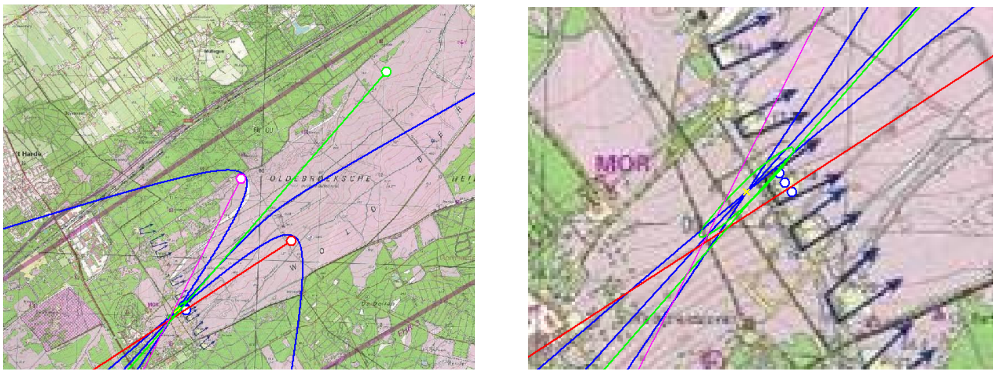

Fig. 5. Computing a launch position at the ASK (3 sensors).

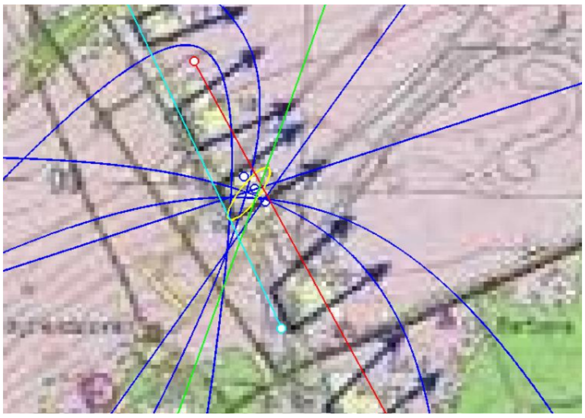

Fig. 6. Computing a launch position at the ASK (4 sensors).

Better results are achieved if 4 sensors are used instead of 3, and if the sensors are placed around the launch position. Figure 6 depicts the computed source position using 4 sensors at 500m,500m, 2 km and 2.5km from the launch position. The error is within 5 meters.

6 Future Developments

The main current effort lies in the development of embedded signal processing hardware to reduce the systems size and battery usage while at the same time, making it more robust, lighter and smaller. The embedded system will be ruggedized to be suitable for wide area surveillance in counterinsurgency warfare: the RAM-LOC system.

Another important development lies in the classification and localization of non-impulsive acoustic sources such as ground vehicles and aircraft. The Acoustic Vector Sensor (AVS) has equally large advantages for these types of sources: it can determine a direction of the source for each frequency bin of a Discrete Fourier Transform (DFT). This makes it possible to draw a time-frequency-angle plot. Here, the horizontal and vertical axes represent time and frequency respectively, the brightness indicates the sound level and the color indicates the direction.

Figure 7 (left) is the time-frequency-angle of a passing rotary wing aircraft. It can be seen that in the lower frequency range, the signals are contaminated by noise from the east. Only the fundamental frequency of the main rotor at 100Hz shows that the aircraft is actually in the west. Above 200Hz, the noise is absent and the source is consistently to the east. Figure 7 (right) depicts the direction of the source based on this higher frequency range, as well as a curve which corresponds to a source flying in a line at a constant velocity. It can be seen that this approximation is accurate up to a few degrees.

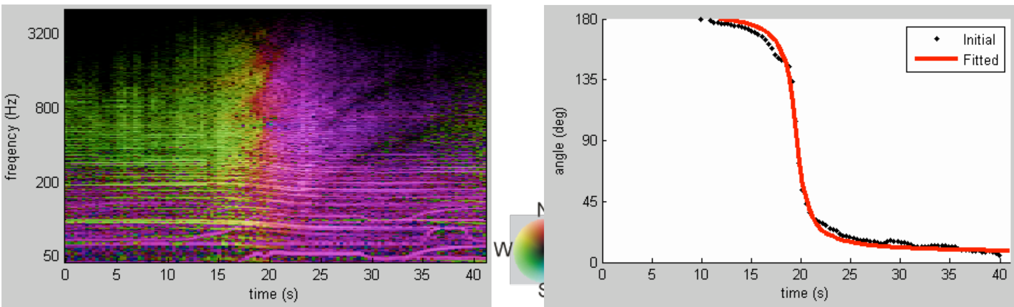

Fig. 7. Left: Time-frequency-angle plot of a rotary wing aircraft. Right: Direction in horizontal plane.

7 Summary

This article considers defense and security applications of the Acoustic Vector Sensor (AVS) with specific attention to the RAM-SCORE system which uses unattended ground sensors (UGS) to determine the locations of launches and impacts at military training grounds and promising results have been presented. Two other platforms have been discussed: the mini-UAV and the ground vehicle. In both cases, the operator can be made aware of any threats and a camera can be pointed at it automatically.

A promising future application of AVS-based signal processing is the use of time-frequency-angle plots to characterize multiple sources simultaneously.