The Acoustic Vector Sensor, a versatile battlefield acoustics sensor

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ABSTRACT

The invention of the Microflown sensor has made it possible to measure acoustic particle velocity directly. An acoustic vector sensor (AVS) measures the particle velocity in three directions (the source direction) and the pressure. The sensor is a uniquely versatile battlefield sensor because its size is a few millimeters and it is sensitive to sound from 10Hz to 10kHz.

This article shows field tests results of acoustic vector sensors, measuring rifles, heavy artillery, fixed wing aircraft and helicopters. Experimental data shows that the sensor is suitable as a ground sensor, mounted on a vehicle and on a UAV.

Keywords: Battlefield acoustics, early warning systems, situational awareness

1. INTRODUCTION

Situational awareness can be extremely difficult to obtain in modern counter-insurgency warfare. To deal with these difficult conditions, high-tech sensor technology is required. New RADAR systems, cameras and acoustic systems are constantly being developed and applied in battlefield applications. However, the two main limitations of all of these new technologies are that they are limited to a single platform such as the ground, an unmanned aerial vehicle (UAV) or a ground vehicle and that they respond to a small number of threats. Typical weapon locating radar only responds to mortars and artillery for example.

Acoustic sensors are sensitive to a unique variety of threats, ranging from mortars and rifle fire to rockets and even helicopters. The large disadvantage of the existing systems comes from the fact that they use spaced microphones to determine the direction. To accurately determine the direction a mortar launch or a helicopter, the system must be at least a few meters in size. Gunshot localization systems are typically about 0.5m across. This does not only limit the number of acoustic signatures that the acoustic system can deal with, but also the platforms that can be used. For example, a 3m mortar localization system cannot be mounted to a small UAV (SUAV) with a 1.3m wingspan.

Acoustic vector sensors measure the direction of the acoustic source directly, 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.

This article is built up as follows. Section 2 considers the history and the current applications of the Microflown sensor. Section 3 considers various acoustic signatures and Section 4 considers several different platforms. Conclusions are drawn in Section 5.

2. THE MICROFLOWN SYSTEM

2.1 History

Invented in 1994, the Microflown sensor is the world’s only true acoustic particle velocity sensor [1]. As can be seen in Figure 1, 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 now 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 2). It consists of 3 Microflown sensors and a co-located pressure microphone. The Microflowns measure the three components of the particle velocity vector, which points towards the acoustic source. Errors of 180° can be avoided by using the sound pressure microphone.

2.2 Hardware and software

Some analog and digital signal processing is required to identify a target and to compute its direction. The required hardware is placed in the field and a wireless protocol is used to send the information to a main station, where the information of several sensors is combined and visualized.

This process is the same for any acoustic signature. One sensor, together with its embedded signal processing is expected to be able to locate and classify mortars, helicopters and all other acoustic signatures. Hence, a new threat can be identified by updating only the software, not the hardware.

Different platforms have different hardware requirements. For example, UAV-mounted sensors must be light and unattended ground sensors must resist heavy weather conditions. On the other hand, the detection, localization and communication software is similar for all of these platforms. The only difference lies in the fact that the UAV’s and ground-vehicles are noisy by themselves such that a specific digital filter is necessary for these two platforms.

In summary, the acoustic signatures all require some tailor-made software but this software can be used for all platforms. Each platform has its own hardware requirements, but all platforms require virtually the same software.

2.3 AVS-based signal processing

Unlike traditional systems, acoustic vector sensors measure direction in a wide frequency range. This means that a detection algorithm can rely on the fact that a source is at the same angle for all frequencies. If two sources are present at the same time, the angle varies with frequency such that multi-events are easily distinguished from single events. In some cases, the sources can even be de-conflicted.
Figure 3 depicts measurement data from the Dutch Infantry Shooting range (ISK). The time and frequency are depicted horizontally and vertically respectively. The brightness represents the amplitude on a logarithmic scale and the color indicates the direction of arrival. The vertical lines in the leftmost figure are caused by gunshots, the horizontal lines are caused by an idling diesel engine, the purple line is caused by a propeller aircraft and the frequency variation is caused by the Doppler effect.

Each of these events can be separated and localized. Firstly, the gunshots are automatically detected and removed. This leads to the center figure. Next, the background level is estimated. This is done manually, by selecting parts of the signal which do not contain the gunshots or the aircraft. The right plot depicts the ratio of the measurement data and the background level, showing only the aircraft. Automated Doppler analysis software can be used to estimate the velocity of the aircraft and the distance to the sensor.

3. ACOUSTIC SIGNATURES

Acoustic signatures for defense and security applications can be divided into several subsets. Firstly, a distinction can be made between impulsive and non-impulsive sources. The set of impulsive noise sources is further divided into low frequency blasts (mortars, explosions, etc.), mid frequency blasts (hand gun, small caliber muzzle blasts) and high frequency impulses caused by, e.g. supersonic bullets. Non-impulsive sources are divided into low frequency tonal sources like rotary wing, or propeller driven aircraft, mid frequency tonal sources like UAV’s and broad banded noise sources like jets and missiles.

3.1 Mortars and artillery

AVS based localization of mortars was studied in a Dutch Ministry of Defence sponsored project in 2009 [2]. The outcome is that it is possible to use Microflown AVS to localize mortars. This was tested at up to 6km distance. In a successive experiment at the German Baumholder Training Area it was shown that the accuracy of a mortar launch localization is below 2 degrees (equivalent to 30m/km), measured in non line of sight conditions, in hilly terrain relatively close to a forest line, see Figure 4 and Figure 5.

With one AVS it is possible to find the direction of a mortar launch and the impact. It is not possible to find its location (because the range must be known for this). With two or more AVS the location can be found with more accuracy than expected from the angular accuracy alone. This is because apart from the DOA information of each AVS the event detection timestamp can be used to further improve the location prediction.

The current status of mortar and artillery localization is that the angular accuracy has been proven to be below 2 degrees in an operational test. The detection range is higher than 6km and with multiple AVS deployed, the localization can be better than 15m/km. The Dutch MoD has acquired a system through an NTP (National Technology Project), consisting of ten unattended ground sensors (UGS) for a shooting range safety and plotting system for incoming mortars and artillery shells. This system is scheduled for completion by the end of 2011.
3.2 Small Arms

Gunshot localization is done by detecting two acoustic events: the shock wave created by the supersonic bullet and the muzzle blast created by the weapon. First trials were conducted by measuring small arms fire from various weapons including 9mm handguns, 5.56mm and 7.62mm rifles, and .50 calibre machine guns. In successive trials real time software was tested. Existing gunshot detection systems use the time of arrival at microphones spaced apart in an array to determine the DOA. This existing method is however, dependent on temperature and wind speed.

In an extensive test of Microflown AVS by a large system integrator, it was proved that the angular accuracy is better than 2 degrees [3]. This test has been repeated with the Dutch MoD in 2010.

A theoretical framework to find the shooter location using the DOA of the shock wave and the muzzle blast has been developed and it was applied to a field test with the Dutch MoD in 2010 (see Figure 6). To calculate range, both the direction and the elevation of the shockwave must be known. Traditional systems appear to have problems with elevation measurements. Apart from not knowing the shooters elevation, this also introduces a problem in calculating the distance to the shooter.

3.3 Rockets and Missiles

A first proof of concept showing that it is possible to detect and localize missiles was established, together with the Dutch MoD, by measuring small civilian rockets. During a later large-scale field test, HOT missiles were launched at 1800m (see Figure 7, top) from the AVS. The noise of such an event is easy to detect at this distance. Stinger missiles were detected and tracked at the Greek NAMFI base (see Figure 7, bottom). The current state of the art is that the launch of a missile can be detected and localized in a range of more than 2km. The impact can be detected and localized at range of greater than 3km.

3.4 Rotary Wing Aircraft

A first field test of tracking rotary wing aircraft by triangulation was undertaken in 2007, [5]. It showed that it is possible to track a helicopter in 3D with only two AVS ground sensors by triangulation of the emitted noise of the helicopter. This method is being developed further in a European FP7 project.

Algorithms to detect helicopters are currently being developed and tested. It is advantageous to make use of the fact that the main rotor generates spectral lines in a wide frequency range, all having the same DOA.

3.5 Propeller driven fixed-wing aircraft

Propeller driven aircraft are assumed to fly in a straight line. This assumption makes it possible to determine an aircraft location with just a single acoustic vector sensor. In 2009, the method was refined by using properties of the spectrum of the emitted noise. It is possible to calculate the Doppler shift as a function of time. With this method it is possible to determine the closest point of the aircraft and the speed of the aircraft [6]. The Doppler method was further refined in
2010 [7]. By using both the Doppler and the direction of arrival (DOA) spectrum as a function of time, it is possible to
determine the speed, heading, altitude, and true RPM of a propeller driven aircraft using a single acoustic vector sensor
(AVS).

A method was developed that eliminates the need to know the acoustic properties of the ground [8]. With the time-
frequency-DOA representation it shows that it is possible to find the acoustic signature of a plane even when the
measurement is disturbed by background noise from gunshots and a nearby diesel engine [7]. Mathematical filters have
been developed that can filter in the frequency domain (e.g. propeller noise), time domain (e.g. gunshots) and in the
DOA domain (an arbitrary sound source in a certain direction) [7].

3.6 Unmanned Aerial Vehicles (UAV’s)
The signal processing of the detection and classification of UAV’s is carried out in a similar manner as for rotary wing
aircraft. A few tests have been undertaken with a civilian UAV, and another study was made in Crete in 2010, where
UAV’s are used as targets for LFX stinger training. In late 2010, a separate field test was undertaken, together with the
Dutch Army, to measure the Raven SUAV under realistic battlefield conditions.

Figure 7: AeroVironment RQ-11 Raven

4. PLATFORMS

4.1 Ground based
The first ground based sensors were used in 2007/2008. Since then the applications have become clear and development
has accelerated. First models were made on a standard tripod, but after the method for cancelling the influence of the
unknown ground impedance was developed, [8] the AVS were placed directly on the ground.

Placing the AVS on the ground has multiple advantages: easy camouflaging, simpler ruggedization, reduced wind speed,
and mathematic models become simpler. The ground based system consists of, apart from the AVS, a mini-computer,
GPS, electronic 3D compass, 3D electronic gravity sensor, 4 channel A/D convertor and a battery.

4.2 Ground vehicle based
AVS can potentially be mounted on ground vehicles (see Figure 8). Differences with the ground sensor are: wind and
platform noise rejection capability requirement, smaller size, powering and geo-referencing from the host vehicle, and
different design.

The initial aim is to integrate the AVS on the camera of a reconnaissance vehicle. A reconnaissance vehicle should not
be easily detected and therefore should use passive sensors where at all possible. With the AVS mounted on the camera
housing it is possible to detect, localize and range various battlefield acoustics (e.g. mortar launches and impacts, RPG
launches and impacts, gun shots, snipers, helicopters and jets, etc.). This increases the reconnaissance capabilities and
offers protection, in the shape of a warning system, to the vehicle itself. It is also possible to detect approaching persons
close by the vehicle and outside the field of view of the on-board camera.
A first prototype of the AVS to be mounted on the Fennek reconnaissance vehicle has been developed as shown above. The total thickness is less than 10mm and the sensor package can be easily and quickly mounted and removed from the camera of the Fennek.

### 4.3 Soldier worn

Soldier worn AVS are being pursued in collaboration with a large system integrator. Helmet, shoulder and rifle mounted options are being explored. The AVS small size and light weight are suitable to the application on these platforms, see Figure 9). The sensor is mounted on the Picatinny railing above the soldier’s left hand.

The objective is to provide an arrow on the periphery of the optics when a gunshot is detected, such that the rifle is then moved in the direction of the arrow, with the arrow subsequently moving to the centre of the sight when the correct bearing and elevation is reached. This allows quick sighting without losing situational awareness by looking away from the sight to obtain the target information.

### 4.4 Based on Unmanned Aerial Vehicles (UAV’s)

In 2009 the idea to put an AVS on a UAV was proposed [9]. The idea to sense and avoid other aircraft was adopted on a broader forum in 2010 (MIDCAS) [10]. First successful tests were carried out in cooperation with Delft University [11].

The UAV application that is being developed at the moment is gunshot and mortar detection and localization from an UAV (see Figures 10 and 11). First test flights have been undertaken [11] and a propeller noise canceling algorithm has been developed. A special wind cap has been developed for mounting on a UAV. In parallel, additional UAV mounted AVS tests are being carried out by a third party in India [19].
4.5 Naval platforms

An underwater acoustic vector sensor is being developed in co-operation with Suasis, in Turkey, in a three year Eurostars program (Hydroflown). The prototype has been tested [12], and the first product to be developed is a sea-bottom based sensor for, e.g. harbor protection (see Figure 12).

Furthermore, a sensor buoy is being developed by Microflown Technologies in another European project. It contains a sensor above water and one underwater. This means that a larger number of threats can be detected and classified. Furthermore, if the event is heard on both sensors, the time difference between the two sensors can be used to determine the distance, using the difference in speed of sound in air and water. Once a threat is localized and classified, a UAV will be launched from a buoy that can survey the threat and broadcast the images to the command centre.

5. CONCLUSIONS

This article considers a large number of experimental campaigns where the Acoustic Vector Sensor is proven to have advantages over conventional acoustic sensor technologies. A wide range of acoustic signatures and the possibilities of various platforms are shown.

6. BIBLIOGRAPHY


