Broad banded acoustic vector sensors for outdoor monitoring propeller driven aircraft

Hans-Elias de Bree[1,2], Jelmer Wind[1], Subramaniam Sadasivan[3]

[1]*Microflown Technologies, The Netherlands, Email: debree@microflown.com*
[2]*HAN University, Department of Vehicle Acoustics, Arnhem, The Netherlands Email: HE.deBree@han.nl*
[3]*Former Scientist – G, ADE, Bangalore, India Email:subramaniamsadasivan@hotmail.com*

Introduction

Permanent and semi-permanent sound level measurements are an increasingly common way to determine environmental noise levels. If the specific causes of sound could be identified, the measurements could be used to improve noise insulation, to tax noise polluters, and to detect possible threats. To achieve this goal, this article proposes acoustic vector sensors. These sensors measure all three components of the sound intensity and the pressure. This system is able to detect and localize noise sources in the entire frequency range. This article shows that these sensors make it possible to classify the sources and also to estimate their location.

Traditionally, only sound pressure transducers were used in acoustics. Directionality can be obtained by deploying a number of spatially positioned sound pressure transducers. The distance between the sensors determines the frequency where such a system has optimal sensitivity.

For several years now, acoustic particle velocity sensors have been commercially available. Acoustic vector sensors can measure both the sound pressure and the 3D acoustic particle velocity in a single point. Such a system has the capabilities to detect noise sources across the entire audible frequency range in a 3D space.

In this paper the detection, classification, localization and tracking of propeller driven aircraft is investigated. The acoustic vector sensor is able to determine the direction of arrival (DOA) of the noise that is produced by the aircraft. That information is combined with the Doppler curve, found in the time-frequency representation of the signals, in order to find the velocity, height and heading of the aircraft.

Acoustic Vector Sensors

An acoustic vector sensor (AVS) consists of a sound pressure transducer (a microphone) and either two or three orthogonally placed particle velocity sensors (Microflowns). If the AVS is placed at a rigid surface, i.e hard ground, the three sensor version is used. This is because the particle velocity normal to the rigid surface is zero. Thus, one AVS has either three or four outputs. Acoustic vector sensors have come to play an increasingly significant role with applications focused on environmental monitoring, border control, harbour protection, gunshot localization, and situation awareness. As compared to sound pressure sensors, acoustic vector sensors have advantages acoustic bandwidth, reduced system size, low data transmission between nodes, and set up times. These benefits have led to a steep increase in practical usefulness of AVS with adoption of simple but powerful algorithms.

Measurement case

Propeller driven aircraft flying at night-time can cause nuisance in an urban environment. To be able to address a complaint it is necessary to know what aircraft (classification) was flying where and in what direction.

The acoustic detection, classification, localization and tracking of aircraft are checked with a Mode-S receiver that decodes the radio signals that are transmitted by most aircraft. This cross check ensures the robustness of the algorithms, finds the aircrafts without Mode-S transponders and it is now possible to quantify the acoustic noise each individual plane produces on the ground: contribution of other sources (cars etc.) are excluded.

An algorithm has been developed that discriminates between moving and non-moving (static) sources. This algorithm is used to filter static acoustic sources. Other sources such as cars and trucks are also acoustic sources that move. These sources are also detected, classified and discarded on the basis of their speed, sound level and altitude.

Outdoor monitoring system

An acoustic vector system is placed outdoors, measuring three acoustic channels with a sample frequency of 48kHz at a 16 bit resolution. The AVS is geo-referenced with a built-in GPS for localization, a 3D magnetic compass and a 3D accelerometer for orientation.

The AVS module is connected by a cable to the power module; a watertight box that includes a 12V battery, a 4 channel data acquisition and an ultra miniature PC with wireless (WIFI) access. The power module measures 25×18×11cm and 18×18×11cm for the AVS module, comprising the AVS and Mode-S receiver.

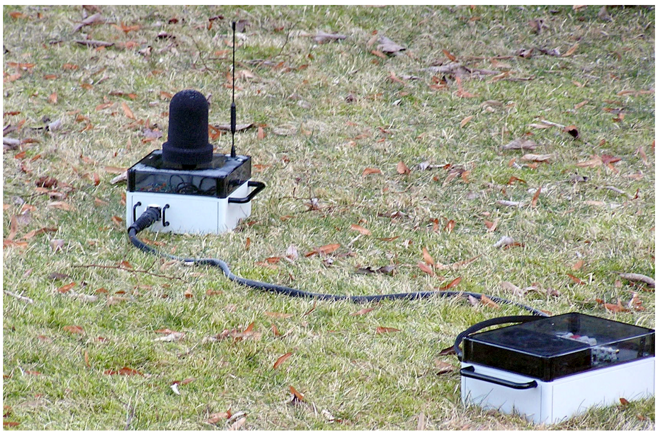

Figure 1: Working prototype of the outdoor AVS measurement system (Velp, NL).

Propeller driven aircraft measured in very unfavourable conditions

The previous example was well conditioned and used to verify the algorithms. As a more challenging example an aircraft is detected during a measurement on a shooting range (shooting noise mainly south west, SW and NW). A truck with idling engine was located 40m SW from the measurement location. The measurement setup is located in a corridor through dense forest.

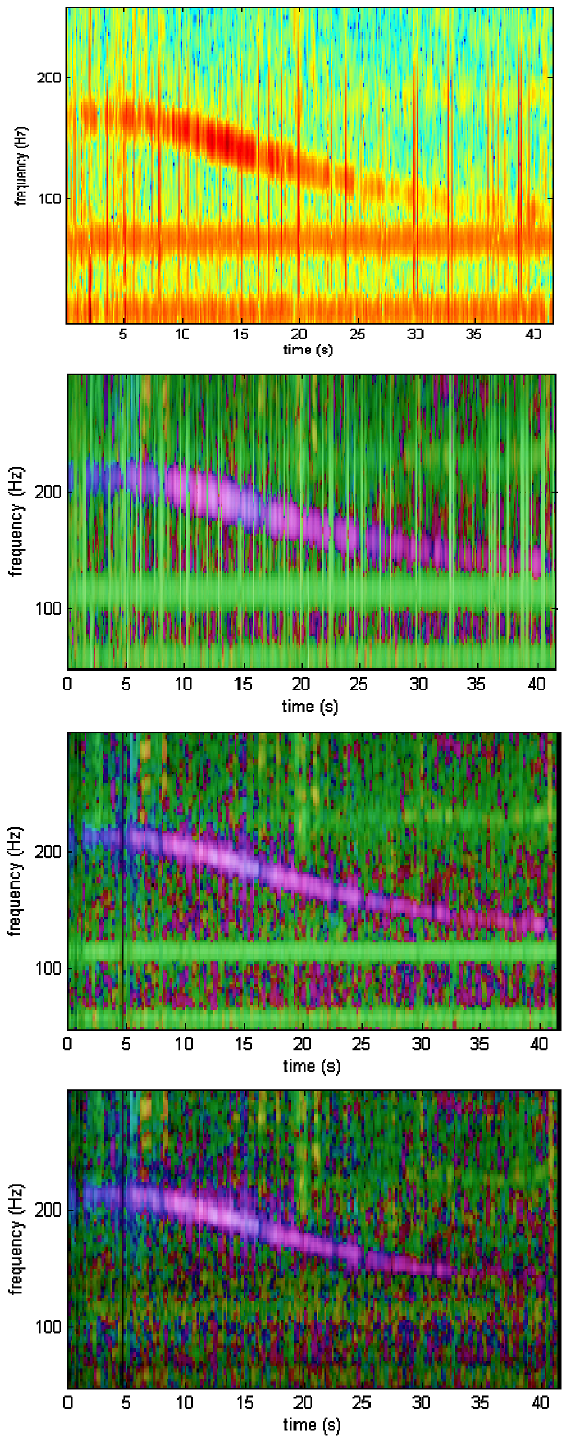

Figure 2: Time-frequency-level representation of a sound pressure signal; time-frequency-DOA representation of an AVS signal (no signal enhancement processing); same but now with gunshots removed; same but now non moving sources removed.

Some results are shown in Figure 2. In the upper graph the sound pressure level is shown in a time-frequency representation. Below that the time-frequency-DOA result of an acoustic vector sensor is shown. In the time-frequency-DOA representation, the aircraft signal shows up clearly as the blue and pink signal with the Doppler signature as it was passing S-SE to N-NE. The green horizontal line at 110Hz is the truck in idle and the vertical lines (mostly green coming from the same direction as the truck) are gunshots.

In the graph below the gunshots are removed and in the lowest graph the static sources are removed from the time signals. The Doppler/DOA remains in noise with a reasonable white spectrum. This signal is well conditioned.

The DOA measurement is inaccurate because of the sensor location in the trench.

A Doppler analysis outcome is that the propeller driven airplane has a speed of 355km/h and was passing (CPA) at 1616m distance.

Conclusion

In this paper a standalone single outdoor acoustic vector sensor system is presented. The system is used for the detection and classification of low flying propeller driven aircraft.

A novel Doppler/DOA (direction of arrival) algorithm is presented. From the sound pressure based Doppler signal analysis alone one can derive a) the speed of aircraft, b) closest point of aircraft and c) the true source frequency.

With the novel Doppler/DOA one can derive:
a) speed of aircraft; b) closest point of aircraft; c) true source frequency; d) the heading of the aircraft; and e) the height/elevation of the aircraft. The airplane elevation and especially the aircraft heading are of course valuable information.

The full paper can be found at [1]

References

[1] www.microflown.com/data/2010_daga_bordercontrol.pdf