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AIRBORNE ACOUSTIC DETECTION AND LOCALIZATION OF TRANSIENTS

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ABSTRACT
Using acoustic sensors for detecting, localizing and classifying noise sources of any kind - and in particular related to potentially adverse activities - is an already well established technique applied in underwater activities. It now appears also as a significant multiplier for airborne automatic detection and localization of warning sounds such as:
- blasts, gunshots or shouts in public buildings such as stadiums, big transportation infrastructures, great and crowded events, VIP protection, etc.
- low altitude aircraft, helicopters, unmanned vehicles, etc. as a temporary or permanent protection of sensitive plants (energy production, telecommunications, military plants, etc.), desert borders, etc.
- snipers and other terrorist fire-arm actions against police forces, international peace corps, etc.
- artillery localization and aggressor identification in cease-fire international verification, etc.

The peculiarities of low altitude sound propagation in air, the numerous echoes in urban and suburban environments, the high level of ambient noise, the variability of atmospheric conditions, make airborne acoustic detection and localization very challenging and specific compared to the underwater sonar know-how.
METRAVIB RDS and its Australian Subsidiary PNV have established an impressive record of experience and applications over the past four years providing to this presentation a real time practice backing.
The key features of airborne acoustic detection and localization of transient sounds is presented together with their practical technological embedded. Typical performance and intrinsic potential and limits of this technique will also be explored.

1. INTRODUCTION AND HISTORICAL BACKGROUND
The use of acoustic waves to detect and localize airborne transient sources started from the hearing evidence of human observers on battlefields, and was first rationalized by the French Pr. Esclangon during the first World War (1914-1918). Most of the critical features were identified at that time, and in particular:
- the multiple paths issues in stratified atmospheres, including some polarity inversion of the waves,
- the interest of the infra-sounds for identifying guns muzzle noise (5 – 15 Hz),
- the use of electro-acoustic sensors as more reliable than the human ear.

The processing was very crude but however effective: each detector was plotted as a line versus time on a single paper roll and the localization of a given artillery battery was extracted from the specific "Z" pattern corresponding to the propagation delays to the elementary sensors. A quick look at the track was sufficient to attribute each shot to one of th various active batteries from this pattern (cf. figure 1) in only a few seconds. Evaluating the battery location on a map was a more tedious topographical exercise... The initial 3 detectors were soon expanded to a typical network of 8 (cf. figure 1) to provide a better robustness from the redundancy. Sensors were several kilometres apart and the deployment was rather tedious (telephone wire transmission, need of a topographical survey).

Little progress was made when the USA introduced the AN/GR8 system at the end of World War II (1944), operated by NATO countries up to 1975. Successful results contributed to the Allies operations in the Russian campaign and later in Korea. It is only with the introduction of the AN/TNS10 system in 1975 that "modern" computer and coded transmissions were available. However, the need for a topographical survey was still a major issue of system field installation. Inertial sensors permitted to solve it only partially. The Vietnam reactivated the interest for unattended sensors (REMBASS, FAALS) with some identification capabilities but never fully developed.

The Persian Gulf war images showed an Israeli demonstrator for detecting masked helicopters, but the huge arrays were non-realistic from an operational viewpoint.

In the recent years, the snipers threats in national (Ireland), or international peace keeping actions (Bosnia) was the priority 1 driving requirement for new developments. Training ranges can also benefit from these techniques.

However, the need for detecting and localizing airborne transient sounds is far from being limited to these military purposes: the protection of VIP's (as a G7 meeting), the security management of crowded stadiums, the terrorist threat as seen in Atlanta Olympic Games, the industrial safety of large chemical plants or oil/gas production rigs, etc., are as well calling for fixed or mobile low cost systems with a fast reaction capability and the following displays:

- the exact location, eventually automatically addressed to a video camera, in elevation and bearing,
- the nature and intensity of the blast, fire arm shot, intrusion noise, etc.,
- the eventual presence of a projectile signature (Mach waves if supersonic), and projectile track, if any.

It was even used recently to solve a court case on the noise burst emission by a metallic roof frame of a private house...

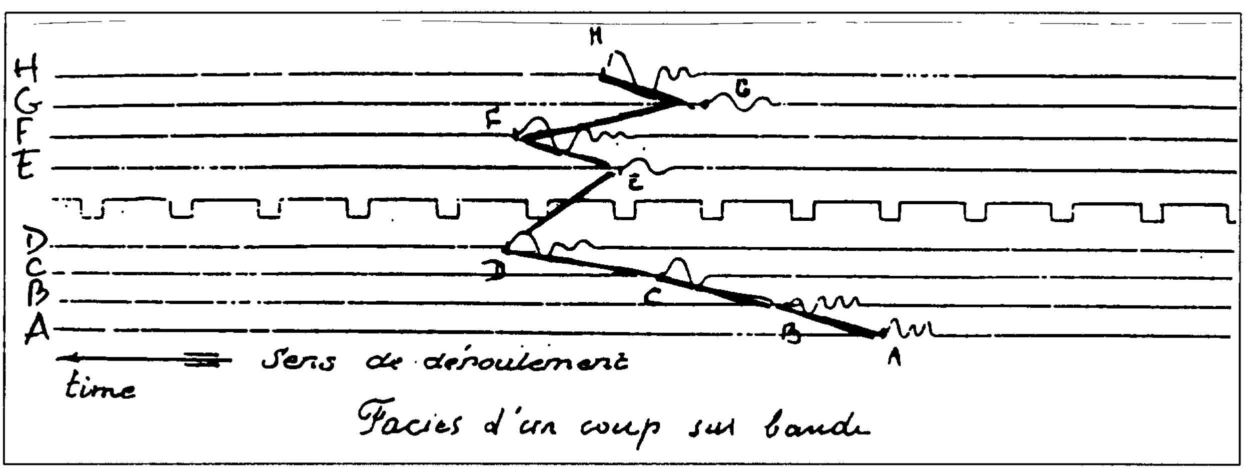

Figure 1: Historical document dating 1917: visual identification of a given artillery position from the time delays on the 8 sensors A to H; every shot from this battery will look alike... (from Esclangon)

2. SOURCES TYPOLOGY

There is a limited list of interesting transient noise sources, each of them with a very specific pattern:

- blast, inducing a strong shock wave but also infrasounds related to the oscillations of the thermal expansion of the associated gas generation (monopole character: volumic generator);
- supersonic projectiles wavefronts, inducing also a strong shock wave, but now conical (speed dependent Mach angle); the real trajectory is no more perpendicular to the wavefront, rising some determination ambiguities; even small calibre arms are now often firing supersonic bullets; missiles and fighters represent the opposite range of Mach waves generators; tables can provide the bullet speed versus distance for every usual calibre;
- impact noise can also be detected, as well as fracture noise, sudden stress release from interfaces, human presence induced shocks, etc.;
- transients of passing or manoeuvring engine noise of any kind (aeroengines, thermal engines, etc.) are another sources family of interest;
- periodic or quasi-periodic transients such as rotor noise of helicopters, propeller noise of aircraft or UAV's, combustion noise of thermal engines, sprocket/track pads shocks of tracked vehicles, etc. are not the limit of transient and stationary sounds; they are mentioned here as some information is to be extracted from the transient wave form to identify early enough their specific type.

The distinction between stationary and moving sources is essential, as the low sound speed in air makes the Doppler effect generally significant. This makes more complex the detection but provides a very useful way to determine the source velocity from the distant acoustic information in addition to the other characteristics such as trajectory, source type, etc.

3. PROPAGATION ISSUES

In a pure, homogenous, calm atmosphere, the sound detection would thus be the definitively perfect approach, providing an omnidirectional passive watching capability at low cost (microphones are not expensive, the amount of data to process is very limited, etc.) and low energy consumption (no moving parts, activation only when something is audible). However, propagation issues limit somewhat the capabilities:

- First, since the low sound speed (340 m/s) is inducing by nature a detection delay of 3 seconds per kilometer; fast sources are thus always detected too late, or at least you have to look for them in another location than the received noise origin...
- Secondly, as for the same reason (low sound speed), the wind speed introduces a significant distortion in the propagation.
- Last but not least, as the temperature differences make the sound propagating not linearly; coupled with some wind induced turbulences, this makes the sound absorption highly variable from one watching point to another at a given distance from the source.

However, the sound propagation also has huge advantages over the infrared, optical or electromagnetic waves, as almost undisturbed by trees, hills, camouflage, etc., and almost impossible to jam or decoy. Even the best gun silencer does not reduce the low frequency muzzle noise generation, and the bullet trajectory also brings back to the sniper...

Just consider by the end a real change in practice between the ground to ground acoustic detection above 3 km, for which the propagation aspects are very critical, and all the other situations (shorter ranges or ground/air and air/ground detection), where the propagation disturbances are much more limited.

An extensive field tests record was established in parallel by the Australian DSTO and by Metravib RDS in Europe, Northern and Southern America, and Asia, in a variety of landscapes, vegetation, soils and atmospheres, providing a clear picture of the effective detection ranges and localization accuracies for the diversity of application scenarios.

The good protection of the acoustic detectors against wind and rain noise is a different issue: it is no longer a propagation problem, but simply a matter of proper technology and sensors engineering.

Adequate propagation models are now available, as PNV-METRAVIB RDS "ENORA" software, supposing a minimum information or reasonable assumptions about the meteorological situation in a given landscape. Simplified at the first order, and coupled to temperature and wind sensors directly attached to the acoustic watching sensor (cf. figure 2), it can provide a direct propagation compensation capability to long distance detection systems.

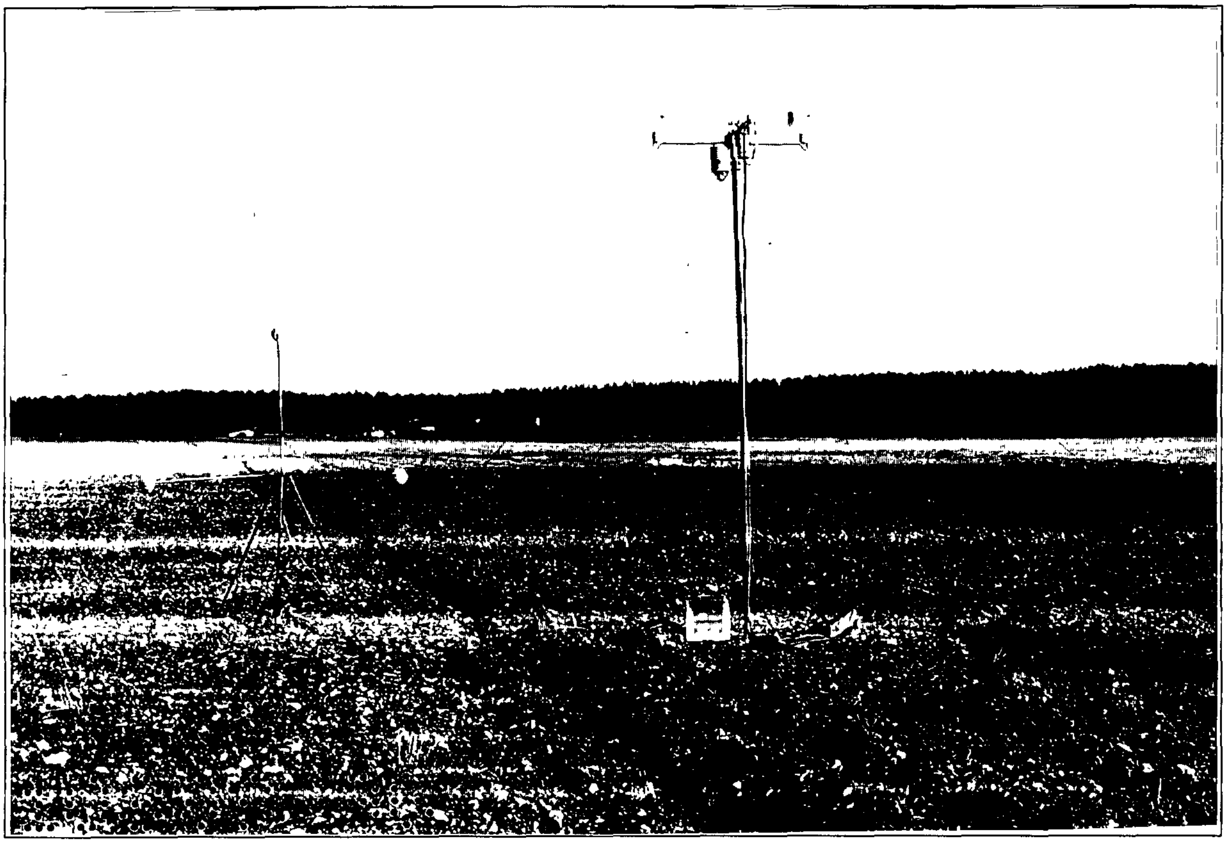

Figure 2:

4. SENSORS AND ASSOCIATED INSTRUMENTATION

As mentioned before, there are some specific features to introduce in the sensor design in order to manage with low current consumption requirements, wind and rain noise rejection, and adequate S/N ratio. They significantly differ from laboratory microphones – and are now also cheaper! But you may understand that the exact design features are commercially sensitive.

In addition to the ambient wind and temperature – and eventually humidity measurements previously mentioned, the most critical associated instrumentation relates to the simplest and fastest field deployment process.

PNV systems are using two options:

- for short range systems, where the distance among detectors is only few hundred of meters, a "beeper" sound generator is associated to some detectors and provides a mutual calibration only from acoustics; a manual compass is used to orientate sensors;

- for long range systems, a differential GPS and a magnetic compass are used, especially developed for the application, together with a radio transmission; covert transmissions may be recommended for military applications – this is a totally secondary aspect, considering the low transmission rate required as each detector is locally processed in order to extract the basic features of the transient signal (direction of origin, exact timing, shape factors…).

As a consequence, the commercial offer of PNV is really versatile, Namely to build the most appropriate package from the precise needs of the customer:

- permanent or temporary security of VIP's meeting places or crowded open air events,
- permanent protection of sensitive buildings and plants,
- permanent watch of industrial plants with blasting risks such as unattended oil and gas production rigs, refineries, chemical plants, etc.
- battlefield oriented systems, either unattended or man operated,
- self-protection units for detecting fire arms threats against vehicles, convoys, helicopters, slow low-altitude planes in dropping missions, etc., most of the time now related to peace keeping and humanitarian missions.

Underwater applications appear also possible for localizing divers or detecting intrusions in the floating cages of fish farms etc.

5. MULTIPLE SENSING ISSUES AND DATA FUSION

Even if well processed acoustic sensors may provide an adequate answer to many requirements, the previously mentioned limits resulting from the propagation issues are sometimes calling for a co-operation with other sensors.

Infra-red detectors are particularly complementary to the acoustic as they are as well passive – thus undetectable – and subject to a completely different pattern of atmospheric disturbances. A French artillery detection system is currently developed to conjugate the thermal and light detection of firing cannons (with the advantage of an instant detection from the light speed) and the acoustic for confirmation, ballistic tracking if possible, and detection of invisible batteries or batteries out of the expected sector of the battlefield (infra-red detectors are not omnidirectional).

Another fully developed system is based on the coupling of the acoustic detection of snipers with a laser illuminating system capable to detect optics of its precision rifle, even before the first shot.

CONCLUSION

The potential of acoustics to contribute to the people protection and improve the immediate management of unexpected hazards is now clearly identified. At the same time, a mature technology is now made available, with well identified leaders for this "niche market" perfectly relevant to SME's. Potential applications are far from being all identified today and we will welcome any other applicative requirements arising from this publication… As the present paper was deliberately excluding an excessively commercial "catalogue" approach, do not hesitate to enquire on the existing products at PNV – this is the best way to determine how contemporary this technology is today.

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