INFRASOUND MONITORING TECHNOLOGIES

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***Abstract**: On the contrary, the infrasonic region of the spectrum is still under investigation. The first studies on the presence of airborne infrasound go back to the end of the 19th century and its effects on the human beings have been investigated since the World War II. This paper reports an overview of the technologies used to detect infrasound in different research fields, pointing out their pros and cons. System specification for urban area infrasound noise monitoring requires transportability, robustness, reduced dimensions to avoid large space occupation and low cost devices for a distributed monitoring.*

***Keywords:** infrasound, low frequency noise, monitoring, technologies, sensor system*

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1. INTRODUCTION

The first investigations on natural infrasound go back to the years following the eruption of the Krakatoa volcano (Indonesia) in 1883 when Verbeekob served some disturbances in several recorded barometric tracks dating back to that time [1,2].

Another famous event occurred in the 1908, when a meteor exploded over the Tunguska River in the center of Siberia. Also on this occasion seismic and pressure waves were recorded in many observatories throughout the world using seismometers, barometers and microbarometers [3]. The first microbarometer called micro-barograph has been developed by Shaw and Dine in U.K. [4].

After the end of World War II, infrasound technologies were mainly developed and used to monitor nuclear explosions. The United States Air Force Technical Applications Center (AFTAC), a military surveillance organization to coordinate the detection of nuclear detonations anywhere in the world, operated a network of infrasound arrays around the world since the 1950s.

In the meanwhile also the instrumentation act to detect infrasound improved by introducing a capacitive microphone [5].

From the 1980s to the mid of 1990s, the researches on infrasound declined dramatically, although a few organizations maintained small, but active, programs and expertise.

After the introduction of the satellite imaging in the early 1980s the study of the atmosphere and the movement of air mass using ultrasound will be confined to the observation of unusual events.

In the 1990s with the subscription by many nations of the CTBT (Comprehensive Nuclear-Test-Ban Treaty) [6], the infrasound research had a revitalizing effect. The Treaty has a unique and comprehensive verification regime to make sure that no nuclear explosion goes undetected. This regime is based on the International Monitoring System (IMS) that consists of 337 facilities worldwide including 60 infrasonic stations distribute as shown in Fig. 1.

These stations have considerable potential for civil and scientific applications, not least in disaster prevention or mitigation.

Fig. 1: The 60 infrasonicstations of the IMS (red dot in the picture) distributed around the world[7]

2. GENERAL STRUCTURE OF INFRASOUND SENSOR SYSTEM

An Infrasound sensor system measures pressure changes over a very large dynamic range and save the acquired data to be transmitted to the base station where it will be processed and analyzed. In particular the IMS characteristics are described in CTBT/PC/II/1/Add.2/Appendix X [8].

The spectrum of an infrasonic wave propagating along the atmosphere can span over four orders of magnitude from 2 mHz to 20 Hz. Signals can be nearly continuous or transitory, and their energy spectrum can vary by more than twelve orders of magnitude (120 dB). The spatial distribution of infrasonic sensing systems may vary from meters to kilometers.

Fig. 2 shows the structure of an infrasound measuring system. It is composed of a noise reducer, an infrasound sensor or an array of sensors [9], a signal conditioning unit, a signal processing unit and a recording and transmitting unit.

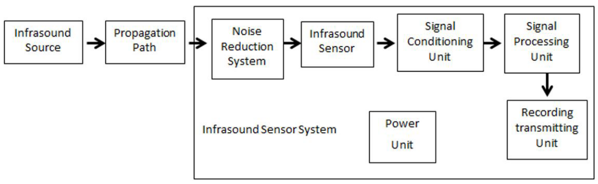

Fig. 2: Block diagram of the measurement chain

3. NOISE REDUCTION SYSTEM

The wind is the main contributor to the infrasound sensor's noise background level. In order to reduce its interferences several approaches can be implemented: wind shield and wind filter (dome, fence, spatial filter and the adaptive wind noise cancellation algorithms, according to frequency interval of interest or the level of attenuation required).

Secondary contributes to the atmospheric ambient noise field are microbaroms. They are the result of a non-linear interaction of oceanic waves with the atmosphere. Similarly, the earth´s ambient noise field consists of microseisms, which originate from the same interaction of oceanic waves.

Both microseisms and microbaroms have a typical frequency of 0.2 Hz and travel over enormous ranges since they are hardly attenuated.

For our monitoring in a urban area we adopted a dome usually as the secondary windscreen. It consists of a hemispherical shape made of open-celled polyurethane foam with the ray of around 0.5 m in order to reduce wind [10] as shown in Fig. 3. alternative solution could be a fabric dome made of porous material has been tested with noise reduction of more than 10 dB in the range 0.3-10 Hz with wind speed less than 6 m/s and in the range 1Hz – 100Hz with wind speed greater than 6 m/s [11].

Fig.3: Dome used in the urban area according to IEC 61400-11[10]

Efficient noise reduction can be achieved by connecting the infrasound sensor to a multiport pipe filter [12, 13], as shown in figure 4.

At the receiver sensor the incoherent fluctuations, such as wind-generated eddies, are reduced and coherent infrasound signals sum up, so that the signal to noise ratio is increased.

The simplest spatial filter is a line filter, shown in Fig. 4a, also called Daniels Filter [14].

Overall dimensions are about 20 ÷ 70 m (it is 20 m for a typical filter that includes 96 inlets distributed in 4 rosettes and 70 m for a filter including 144 inlets arranged in 8 rosettes) which are not suitable in our application.

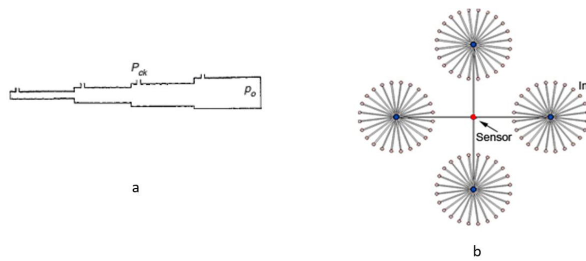

Fig. 4: a) Daniel filter b) Example of pipe array multiport spatial filter, also called rosette filter, with 96 inlets ports

A wind fence enclosure is a structure constructed around the infrasound sensor made of solid or porous material, as shown in figure 5 that acts as a barrier to the wind[15,16]. Wind noise is reduced due to the energy loss of the air mass moving inside the fence, transferring the energy to the walls of the fence. While infrasound wave amplitude is less affected by the structure of the fence wall. It is required to keep low the transmission loss of the incident infrasound wave. The drawback of this shield again is the high area occupation, so at the present, it has not been adopted.

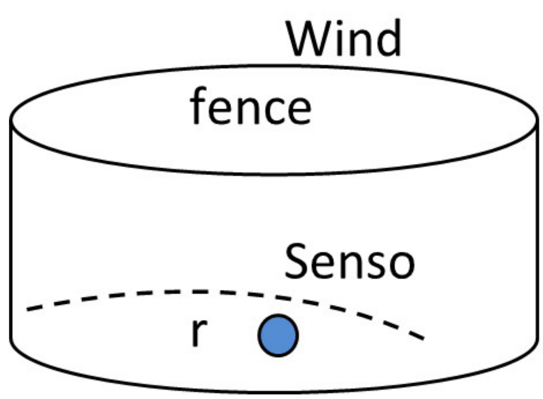

Fig. 5: Wind fence enclosure

4. INFRASOUND SENSORS

For infrasound detection many transducers have been developed such as microbarometer, piezoelectric and condenser microphone (see Fig. 6), each one with different performance regarding sensitivity, bandwidth and self-noise (see Tab. 1).

Sensor	Microbarometer	Piezoelectric microphone	Condenser microphone
Transduction principle	Output electric signal generated by LVDT (linear variable differential transformer) Coupled to Aneroid Cell	Piezoelectric effect, output electric signal by mechanical deformation	Output electric signal generated by capacitive variation
Frequency band [Hz]	0.01 ÷ 50	0.0005 ÷ 100	0.1 ÷ 20 k
Sensitivity [mV/Pa]	20 ÷500	1 ÷10	5 ÷ 50
Self-noise [mPa]	2 (0.02 Hz ÷ 4 Hz)	0.1 (0.02 Hz ÷ 4 Hz)	0.2 (full band)
Description	Higher sensitivity than piezoelectric and condenser microphone, but it presents the highest self-noise. Its use is required in the IMS Infrasound Stations	Low sensitivity, low electric noise, lower bandwidth than a condenser microphone	Highest bandwidth capacities; Less sensitive and lower self-noise than a microbarometer

Tab. 1: Infrasound detection instrumentation technologies
Fig. 6: a) Aneroid Cell; b) LVDT sensor; c) Piezoelectric sensitive element; d) Capacitive sensor

5. SIGNAL PROCESSING UNIT

During our monitoring campaigns we used a prototype station based on a portable PC connected with an external acquisition card (Sinus Apollo Box) enclosed in a portable case accomplish to IP65 standard. One or more infrasonic microphones (G.R.A.S. 40HF or 46AZ according to their frequency and sensitivity).

With their proper preamplifier are connected to the acquisition card. All data are acquired, analyzed and the results stored and send to the base station.

System frequency range starts at 2 Hz with sensitivity less than -2 dB; Fig. 7 shows an example of the acquired signal spectrum.

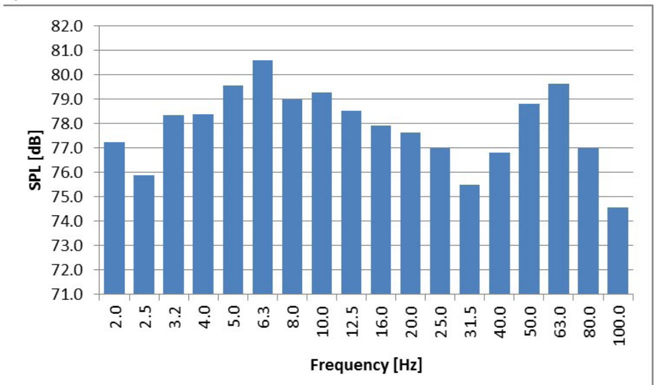

Fig. 7: Example of acquired spectra

The function of the signal processing unit is performed by a PC as a remote station (figure 8). It is designed to filter the acquired signal to reduce the noise and to extract its features both in the time and in the frequency domains, such as amplitude, spectrum, main period, azimuth, etc. Furthermore, the filter section has the role of weighting the signal, using for example the G curve, or to de-convolve the signal with the calibration curve [17]. The G weighted curve is used to evaluate the impact of the infrasound for the human being health risk assessment [18].

When more than two sensors are used the processing unit is able to triangulate signals in order to identify the arrival direction of the wavefront.

Usually, data at the raw level are treated and stored continuously, as in the ISM station [19], for further analysis. At the user-level, one of the most important functions is the detection function, used to mark and identify a single event.

The advantage of using a personal computer is that it is able to perform high-level processing, thanks to both its power computation and the number of recorded temporal series, coming from one or more stations located in different sites. Users can collect all those information to create an infrasonic map of an area, influence diagrams, or evaluate the risk connected to the infrasonic exposure [20, 21, 22].

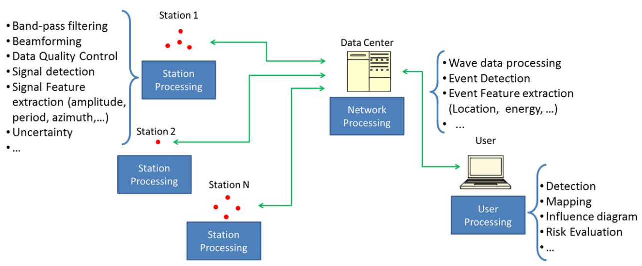

Fig. 8: Different levels of processing: Station Processing, Network Processing, User Processing

6. RECORDING AND TRANSMITTING UNIT. POWER UNIT. CALIBRATION

In our system, raw or treated data are acquired and saved continuously. As the memory of the measurement system is limited, data are locally stored temporarily and then sent to the data center to be collected and processed together with the data coming from other stations, as shown in Fig. 8. Each sent data packet is formatted using a header, containing at least sensor and station identification, time reference, and sample rate, followed by signal information such as the time history and infrasound features.

The time synchronization of the stations could be performed by a GPS module, also included in a smartphone or less accurately by a connection with a time server via the web.

Usually, as the station is placed in uninhabited areas or areas not reached by a cable data network, the data transmission is performed by a radio unit, and not via cable, connected to the network infrastructure.

The power unit is designed to supply energy to all the units of the measurement system. As these systems work in an isolated place and far from the power grid, they need an independent power source. Usually, energy is provided by a battery or both battery and solar panels for battery recharging.

Furthermore, the battery has the advantage to reduce electrical noise coming from the electric network.

Reference calibration method for a microphone in the range of 2 Hz – 25 kHz is described in the IEC 61094 part 2 [23]. Outside this range, there is no primary standard. CEA [24] and NPL [25] suggest their method in order to calibrate sensors below 2Hz with overall uncertainty less than 0.5 dB.

7. CONCLUSIONS

Several studies there are in the literature about infrasound and their use to detect explosion or impulsive shock events, thanks to their low absorption in the atmosphere so that they can propagate also around the Earth many times. This has led to the development of many infrasound stations around the world focused on the band of 0.01 Hz – 4 Hz. Today with the improvement of technology, mainly piezoelectric sensors and capacitive microphones, measurement systems have become cheaper, portable and easily installable, allowing spot measurements in a different point of large areas or cities to create a detailed map. The goal of the implemented system is to map infrasound in an urban area as a useful instrument in studies on the health and safety of working and living environments.

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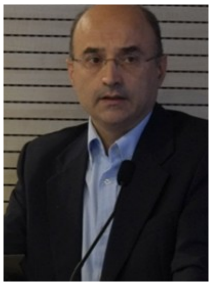

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