DESIGN OF A PROTOTYPE OF A SMART NOISE MONITORING SYSTEM

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The paper describes the new smart noise monitoring system designed and implemented into the project named LIFE15 ENV/IT/000586 "Methodologies fOr Noise low emission Zones introduction And management" (LIFE MONZA). The prototype system has been designed keeping in mind the state of the art systems and the monitoring needs of the LIFE MONZA project. The designed system can be considered as a prototype according to the necessary customization in the designing of connections among the hardware components and in the definition of protocols to manage and post process of collected data. The prototype is expected to undergo quite a long testing phase (up to five years) during and after the LIFE MONZA project duration. In this paper, some details related to the designed network are reported. In particular, a detailed definition of the hardware components and specs, the transmitting data techniques, the specifications necessary to collect raw data are described. Furthermore some new procedures to periodically check the noise monitoring system performance are proposed.

Keywords: environmental noise, smart monitoring system, prototype

1. Introduction

Currently, noise is considered as one of the most dangerous pollutants affecting urban realities. Important contributes to manage this issue has been given by some concluded European projects such as LIFE+2010 QUADMAP, LIFE+2008 HUSH and LIFE+2009 NADIA [1] [2]. As an additional contribution LIFE MONZA project (Methodologies fOr Noise low emission Zones introduction And management - LIFE15 ENV/ IT/000586) aims at developing an easy-replicable method and related guidelines, for the identification and the management of the Noise Low Emission Zone, an urban area subject to traffic restrictions, whose impacts and benefits regarding noise issues will be analysed and tested in the pilot area of the city of Monza, located in Northern Italy. LIFE MONZA project foresees to carry out some noise monitoring activities planned in a pilot area, referring to standard methods, using sound level meters of class I precision, and also by developing and using a smart low-cost monitoring system.

As a preliminary action, the state of the art about smart noise monitoring systems has been investigated, in order to understand the accuracy, the performance and the maintenance features characterizing this kind of devices. Then, a new smart noise monitoring system has been developed in order to be used as a continuous monitoring network in the ex ante and ex post scenarios (one year + one year) into the pilot area of LIFE MONZA project. At the end of the LIFE MONZA project, the prototype will be given for free to the city of Monza that will take care of using it for monitoring activities in the three years after LIFE period.

2. State of the Art about smart low-cost noise monitoring systems

In order to support the development of the prototype, a survey of the most advanced noise smart and low-cost monitoring experiences and procedures carried out in Europe has been conducted [3].

The traditional methods of environmental noise monitoring, according to requirements provided by International standard [4], employ long and short measurements time periods, using expensive equipment for measurements and data management, whereas new noise monitoring methodologies, able to permit lower costs, widespread and long-time measurements and good quality output data, have been developed. The recent developments of low-cost microphones and computing devices and the availability of web resources give the opportunity to create noise measurement devices networks using a “smart low-cost sound monitoring approach”. These systems seem to be competitive, in some situations and under defined conditions, compared to the traditional ones.

The Noise Low Emission Zones, as urban areas characterized by road traffic restrictions, should be the correct scale for sensors networks applications and LIFE MONZA project, providing noise monitoring activities in a pilot area conducting by traditional method and also by a prototype of smart low-cost monitoring system, will give a contribution, analysing the efficiency of the monitoring system and allowing data comparison.

From this point of view, many experiences are in progress and a comprehensive analysis of methods employed. However, results achieved and the definition of common procedures are not fully developed and shared yet.

The development of a low-cost network is commonly based on an embedded low cost mini pc, equipped with a sound board, with Wi-Fi capabilities (or GPRS/3G/4G) and a signal analysis software able to process the sound data. In this kind of networks, low cost microphone, as MEMS (Micro Electro-Mechanical Systems), are generally used, but the characteristics of the system components tend to become obsolete in a very short time period.

The networks have been analysed mainly referring to the following ones: DREAMSys (website: http://projects.npl.co.uk/dreamsys/)[5]; The smart monitoring network developed by Ghent University [6]; Senseable Pisa [7]; Life DYNAMAP (website: http://www.life-dynamap.eu/)[8], Barcellona noise monitoring network [9], Low-cost monitoring systems based on smartphone devices developed by the Regional Environmental Agency of Piemont [10]. These projects highlight strengths and weaknesses of smart low-cost noise monitoring systems. The low-cost noise monitoring sensors proved to be suitable for widespread and long-term noise assessment activities and, compared to standard noise monitoring networks adopting Class I sound level meters, the lower costs of the devices are evident. However, installation, maintenance and quality control costs should be taken into account especially in view of the long term period of measurement and so as to maintain the necessary reliability and stability.

Long-term stability, defined as the difference between the measured values obtained at the beginning and at the end of a defined measurement time period, mainly due to the effect of prolonged outdoor exposure, is the most relevant weakness of the smart sensors. Noise monitoring sensors need to be periodically recalibrated, requiring maintenance visits and, in order to avoid measurement data inaccuracy due to deviations from the calibration value, self-calibration methods (currently one of the most investigated research topic in this field) have been developed.

From the analysis of the projects mentioned above, Table 1 can be derived, summing up main features and technical specifications of the sensor networks.

Table 1: Smart low-cost noise monitoring systems - main characteristics arising from analysed projects.

Smart low-cost noise monitoring systems **main characteristics arising from analysed projects**	
Parameter or feature	**Value**
Short /long term noise measurement	long term noise measurement
Embedded pc monitoring system /Units with microcontroller and digital signal processor	Embedded pc monitoring system
Type of microphones	MEMS microphones ¼ - inch condenser low cost microphone
Time basis acquisition	Different values. In most frequent cases = 1 *s*;
Acoustic dynamic range	70 dB
Acoustic Measure range	Different ranges. 30 (40)-100 (110) dB(A)
Acoustic frequency range	20 Hz-20 kHz
Floor noise value	30-35 dB(A)
Tolerance	LAeq ±2 dB(A)
Acoustic indicators	In all cases studies: L_{Aeq}, L_{A10}, L_{A50}, L_{A90}; In some cases studies: $L_{A01;}$ L_{Ceq}, M_{60}, M_{70}, N_{cn}
Spectral data	1/3 octave
Calibration	Periodic calibration
Additional characteristics	
weatherproof	guaranteed in all case studies
connectivity	Wifi/3G/4G
possibility of audio recording	Applied in some case studies
other properties	equippable with temperature/humidity sensors, air pollution monitoring sensors, GPS logging etc; battery for energy storage.
Shape of PCB	Optimized to avoid diffraction effects
Pilot area of implementation	
Urban/Suburban	Urban and sub-urban areas
Territorial scales	Different dimensions, from medium to large scale; (most frequent dimension in urban area: ≈1.00 km^2)
Number of stations	Different situations. For areas of medium spatial dimensions, in most cases, from 5 to 20 units

The results show that it is possible to find a satisfactory frequency response in the range from 20 Hz to 20 kHz and floor noise value of 30-35 dB(A). The low-cost sensors show very frequently their compliance with Class II requirements, according to IEC 61672-1 standard, but further studies, allowing to compare output data obtained by standard and low-cost networks, are needed.

Considering the different characteristics analysed, in most cases the ranges of values, noise indicators and field of applications are very different and it is difficult to identify common specifications.

In the future, the typology of noise monitoring activities where it is possible to apply the low-cost sensors must be defined, the suitable territory scale of deployment, and related specifications, should be analysed in depth and common procedures must be developed and shared.

3. Noise monitoring network: specifications and design

The pilot area to be monitored consists of a district of the city of Monza as shown in Fig. 1.

Figure 1 : Perimeter of the pilot area ("Libertà" district, city of Monza).

In the selected pilot area a main road (Libertà street) and roads affected by medium-low traffic are present. Significant average levels of noise pollution affect a large number of citizens so that Libertà district is identified as a hotspot in the Action Plan of the city of Monza. The noise strategic map of the city of Monza, dated 2012, highlights that in a range of 30 m from the Viale Libertà almost the 100% of the receivers are exposed to levels higher than 65 dB(A) during the day and 55 dB(A) during the night.

The Smart Noise Monitoring System (SNMS) network is meant to adequately cover the pilot area and the different types of roads. Secondarily, the possibility to have a connection to the electric energy network (avoiding the use a solar panel) is considered as an added value for the selection of measuring positions.

From a practical point of view, 10 monitoring stations are expected to be installed in the pilot area of Libertà district, as illustrated in Fig. 2. In particular, 2-3 microphones will be placed along the Viale Libertà, the main street where the traffic flow mix is expected to mainly change from ante to post operam scenario. The other microphones will be uniformly distributed along other streets belonging to the pilot area.

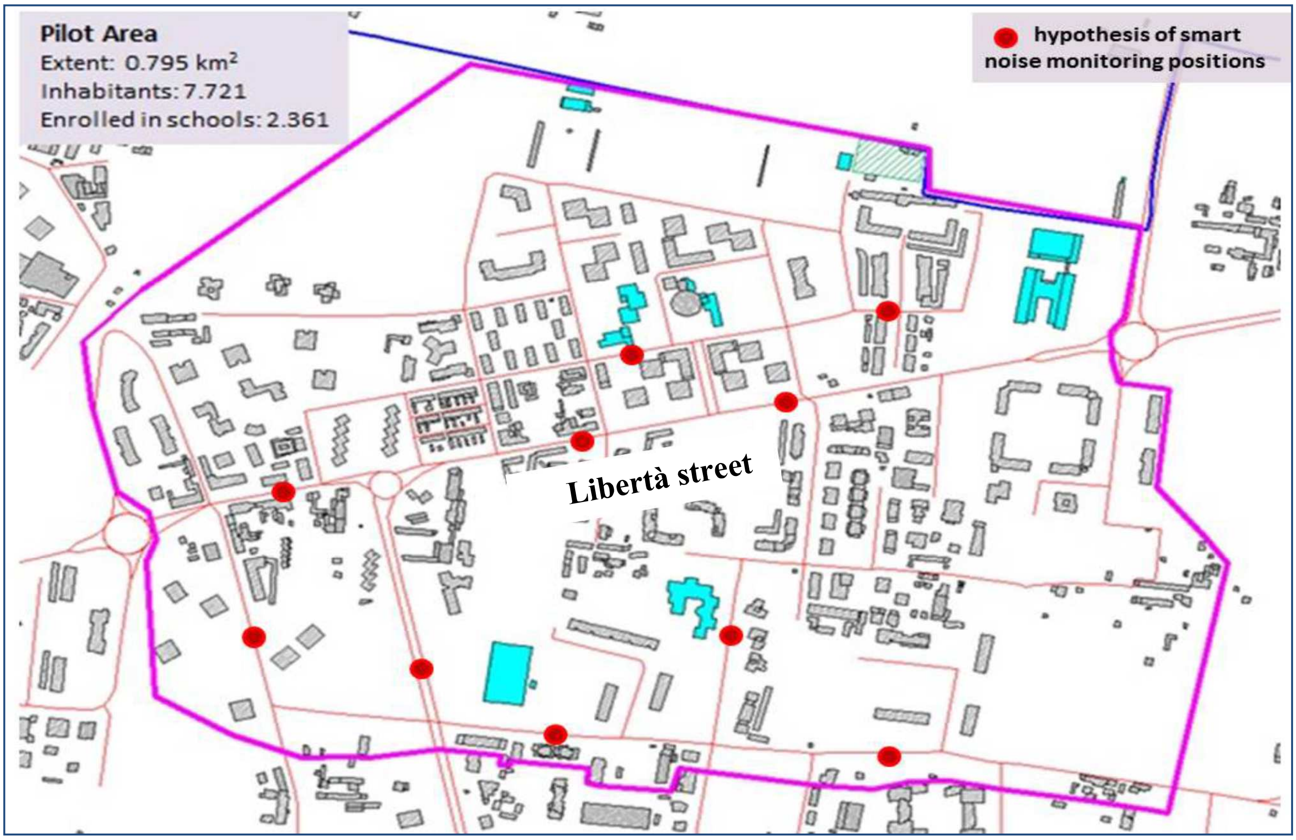

Figure 2: Site plan with the identification of noise monitoring stations.

4. Noise monitoring unit: specifications and design

The SNMS technical specifications were defined keeping in mind the aim of a long-term monitoring of acoustic parameters. These are expected to be useful both to understand acoustic climate in the pilot area and also to validate the noise maps calculated for ante and post operam scenarios by means of road traffic data as input.

According to the previous general requirements and to the outcome of the state of the art analysis described in Section 2, the following main specifications of monitoring units are defined:

- acoustic parameters: overall A-weighted continuous equivalent sound pressure level, “LAeq” and continuous equivalent sound pressure level, Leq, as 1/3 octave band spectrum data;
- timing for data recording: data will be acquired with a time basis of 1 second in order to permit the recognition of unusual events in the eventual analysis phase;
- timing for data transmission: data will be sent to the remote server every one hour;
- data transmission network: the data will be transmitted through the 3G cellular telephonic network;
- power supply: solar panel (max expected size 60cm x 60cm) and battery for energy storage or direct connection to electricity network;
- sensors location: on streetlight or on façade, height 4 m above the ground level;
- sensor type: ¼ or ½ - inch low-cost microphone with removable rain protection;
- floor noise < 35 dB(A);
- frequency response at nominal frequencies of 1/3 octave within the class I specs ± 1dB.

Starting from the specs listed above, the monitoring system architecture has been mainly based on monitoring units designed in the Life DYNAMAP project (these units comply with all the specs), tailoring the data transmission, storage and post-analysis to the needs of the LIFE MONZA project (this latest aspect is not dealt with in the present paper).

Referring to the hardware components, each monitoring unit is designed to achieve a high energy efficiency and low computational burden. In particular, it has an average variable electric absorption among 200 mW and 400 mW and can be powered through the solar panel (size 30cm x 35cm) and an integrated power battery with the possibility of being directly connected to the electricity network. These units are equipped with a low-power microcontroller able to perform, by mean of IIR digital filtering, the calculation of the A-weighted continuous equivalent sound pressure level “LAeq” and, by mean of FFT, of the 1/3 octave band continuous equivalent sound pressure level.

In the usage scenario foreseen for the pilot area, the units will periodically (every hour) connect to the internet and transfer the gathered acoustic data, together with statistics on battery level and quality of the transmission signal. The data will populate a dedicated database, optimized for handling large amounts of data. It has been also planned to build up a web application that allows visualization of the location of the control units on a navigable map, data representation and download.

5. SNMS verification

As already mentioned, the low-cost sensors challenge consists in maintaining network performance during long term periods of outdoor operation.

A periodic check of the system will be performed to understand if the measurement accuracy is maintained in time or if sensors need to be repaired or replaced. Two system check procedures are proposed to verify the noise monitoring system performance:

- a preliminary check procedure;
- a long term in situ verification procedure.

The preliminary check will be performed for a reduced time period (2 months) before the monitoring period in the pilot area starts. The long term in situ verification is planned to be performed during the noise monitoring period in the pilot area (2 years: 1 year in the ante-operam scenario and 1 year in the post-operam scenario).

Furthermore, at the end of the project, the prototype will be given for free to the municipality of Monza that will take care of using it for monitoring activities in the three years after the project end. For research aims, partners of LIFE MONZA project will evaluate to continue the long term verification until to end of monitoring activities.

5.1 Preliminary check of the performance maintenance

Two kinds of time-stability checks are planned to be performed during the first two working months (once a week):

- Check n.1 – a calibration check @ 1 kHz (by using a sound pressure class I calibrator). Requirement: the sound pressure level should stay within 0,5 dB from the calibration level;
- Check n.2 – a comparison between LAeq,60s obtained from low cost sensor and class I microphone recording an environmental noise in the range 45/105 dBA.

The proposed requirement is based on the parameter, “LAeq,60s”. In particular, the difference between “LAeq,60s” determined by using SNMS sensor and class I instrumentation has requested to be within 1,5 dB(A).

The procedure to perform the comparison, the best position and direction of class I microphone to perform a good comparison are currently under discussion.

5.2 Long term verification

The previous two time-stability checks are proposed also for long term in situ verification, on a 3 months basis, during the first two monitoring years. If a sensors will not comply with these requirements, the sensors will be repaired or replaced with new ones.

In particular, referring the long term verification, it is under discussion the necessity of first calibration (Check n.1) or if this check could be eliminated or replaced by other type of check which does not ask for in situ activity. In fact, while the Check n.2 is probably manageable from the ground, the check n.1 needs that the operator works at sensor height level (4 meters on the ground) with a consequent increase of practical difficulties.

6. Conclusions and future works

The state of the art about smart noise monitoring system has been investigated and the results have been summarized in the paper.

Smart low-cost noise monitoring systems, allowing an extensive and long-term noise monitoring, in medium sized territorial scale as urban area, seem to be able to ensure a satisfactory quality output measurement data.

In particular, according to the objectives of monitoring activities of LIFE MONZA project, a smart noise monitoring network has been designed and developed; the resulting technical specifications have been presented in the paper.

Moreover, some procedures to verify the performance maintenance have been proposed and will be tested on the prototype system. An optimization of the time stability check procedures will also be carried out, based on the analysis of results coming from preliminary and long term verification check implementation.

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