LIFE DYNAMAP: an overview of the project after two years working

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ABSTRACT

In 2014 the LIFE DYNAMAP project moved its first steps towards the development of a system able to detect and represent in real time the acoustic impact of road infrastructures. Aim of this project is to ease and reduce the cost related to the update of noise maps required by the European Directive 2002/49/EC on environmental noise. To that end, an automatic monitoring system, based on customized low-cost sensors and a software tool implemented on a general purpose GIS platform, was foreseen to be developed and built in two pilot areas located along the A90 motorway that surrounds the city of Rome (Italy) and inside the agglomeration of Milan (Italy). After two years working, focused on the design of the system and the development of hardware and software components, the project is now approaching the next experimental phase where the first prototype of the Dynamap System will be installed and tested. A one-year survey will then be undertaken to check the reliability, effectiveness and efficiency of the system. In this paper, a general overview of the project, of its progress and of the main results achieved so far are described.

Keywords: Dynamic noise maps, road noise, real time monitoring I-INCE Classification of Subjects Number(s): 52.3; 76.1.1

1. INTRODUCTION

The DYNAMAP project (Dynamic Acoustic Mapping - Development of low cost sensors networks for real time noise mapping) is a LIFE project aiming at developing a dynamic noise mapping system able to detect and represent in real time the acoustic impact due to road infrastructures. Scope of the project is the European Directive 2002/49/EC relating to the assessment and management of environmental noise (END) (1, 2), enforcing Member States to provide and update noise maps every five years in order to report about changes in environmental conditions (mainly traffic, mobility and urban development) that may have occurred over the reference period. The update of noise maps using a standard approach requires the collection and processing of many new data related to such changes (3). This procedure is time consuming and costly and has a significant impact on the financial statements of the authorities responsible for providing noise maps. Therefore, cheaper solutions are required in order to reduce the cost of noise mapping activities.

To meet such requirements and the growing demand of information about noise pollution, the Dynamap project foresees the development of an automatic noise mapping system delivering short-term (real-time dynamic noise maps), as well as long-term noise assessments (annual evaluations). Despite real time noise maps are not explicitly required by the END, their automatic generation is estimated to lower the cost of noise mapping by 50% with added significant benefits for noise managers and receivers, such as the possibility of providing updated information to the public through appropriate web tools or the opportunity to abate noise with alternative measures based on traffic control and management.

While this approach seems quite promising in suburban areas, where noise sources are well identified, in complex urban scenarios further considerations are needed to make the idea feasible.

In the past the possibility of implementing dynamic noise maps was partially tested using standard sound level meters and expensive acoustic calculation software with questionable results, but such a solution has never been tested on a large scale with low cost customized devices and a general purpose

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GIS platform for data processing and system management, as the Dynamap project suggests.

2. THE DYNAMAP PROJECT

2.1 The main idea

The main project idea is focused on the research of a technical solution able to ease and reduce the cost of noise mapping, through an automatic monitoring system, based on customized low-cost sensors and a software tool implemented on a general purpose GIS platform, performing the update of noise maps in real time (dynamic noise maps) (4).

The update of noise maps is accomplished by scaling pre-calculated basic noise maps, prepared for different sources, traffic and weather conditions. Basic noise maps are selected and scaled using the information retrieved from low-cost sensors continuously measuring the sound pressure levels of the primary noise sources present in the mapping area. A complete basic noise map covering the entire survey area is calculated and saved for each source. Scaled basic noise maps of each primary source are then energetically summed-up to provide the overall noise map of the area. In this way, the need for several and expensive software license is extremely reduced and limited only to the preparation of the basic noise maps.

In order to decrease the costs of the entire mapping process, the DYNAMAP project involves the development of customized low cost devices to collate and transmit data, and the implementation of a simple GIS based software application for maps scaling and sum with reduced calculation load. Such a standalone dynamic mapping software, together with low cost noise monitoring stations, makes the DYNAMAP system a very efficient and versatile noise mapping tool, virtually able to interface any existing or future noise modeling software, including the new European model CNOSSOS, which is expected to be operative for the 2022 round of END. The DYNAMAP system provides also for some unique characteristics that are not available in commercial products, like algorithms for eliminating spurious events (recognizing and masking unwanted events: i.e. occasional noise, etc.), traffic model data features, and future adaptability to other environmental parameters. In figure 1 a schematic representation of the DYNAMAP system is shown (5).

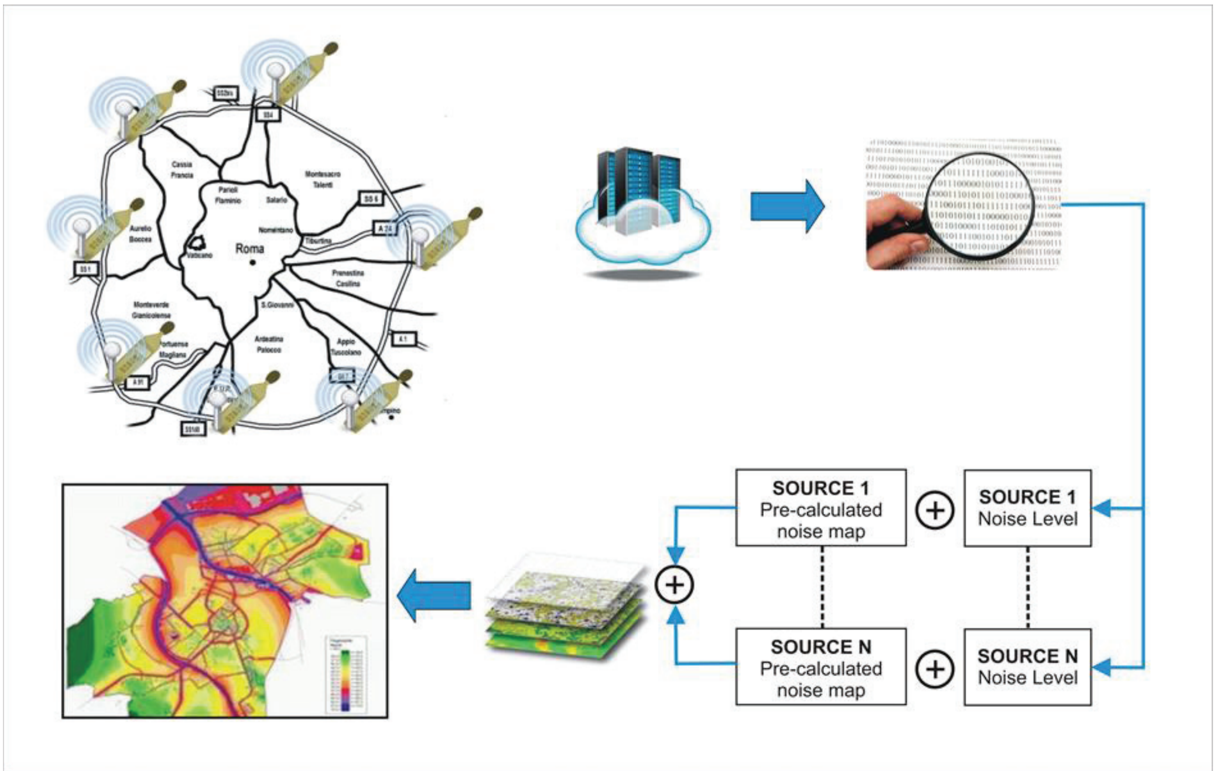


Figure 1 – Schematic representation of the DYNAMAP system

2.2 The objectives

The main goal of the project is to demonstrate that noise maps can be automatically updated in real time using low cost sensors and a general purpose GIS platform. To that end, the project foresees the development of customized sensors and communication devices, in order to reduce the cost of the monitoring network, as well as the implementation of an advanced management and reporting interface to update noise maps and inform the public, thus eliminating the need for expensive dedicated acoustic software for data processing.

The feasibility of project's objectives will be proved implementing the system in two pilot areas with different territorial and environmental characteristics: an agglomeration and a major road. The first pilot area will be located in the city of Milan and will cover a significant portion of the town including different type of roads and acoustical scenarios. The second pilot area will be located along a major road, i.e. the ring road surrounding the city of Rome. About 25 sensors will be installed in each pilot area to provide noise levels information and dynamically update the noise maps. The two pilot areas will be monitored for at least one year to check the reliability and accuracy of the system. Fault events will be also analyzed in order to detect system malfunctions and define the specifications for future upgrades of the monitoring sensors and of the system as a whole.

As a secondary objective, the project aims at demonstrating that dynamic mapping can be also applied to monitor and report the information related to other environmental parameters, such as those related to air quality, meteorological conditions, traffic, etc. To test this option, two monitoring sites will be equipped with additional sensors to assess the feasibility of feeding and integrating the dynamic mapping system with multiple information.

Finally, the Dynamap project intends to provide a web software application to inform the public on noise issues. To guarantee the full effectiveness of this application, a group of selected users will be monitored to check the accessibility of the system and help developing a user-friendly interface for public information. The system will be validated by testing stakeholders ability in managing the tool and assessing their agreement through ad hoc tutorials. Case studies related to the most common environmental problems will be proposed in order to assess the effectiveness of the dynamic mapping system. The general public will be also involved in the project monitoring to evaluate the system versatility and its contents comprehensibility.

2.3 Added value and expected benefits

The main added value that can be attributed to the project is the automation of the noise mapping process and consequently the potential reduction of the effort required to central and local authorities to provide updated noise maps. The automation of the noise mapping process using a low cost monitoring network and a software application implemented in a general purpose GIS platform, is expected to contribute also to abate costs and reduce the time needed to update noise maps.

Another issue that makes the Dynamap System particularly valuable is the possibility of providing faster response to noise mitigation requests or even immediate actions in case of high noise levels. As a matter of fact, the real time monitoring of noise levels can be effectively used to generate alert signals and drive ITS systems interface to smooth traffic, for instance by remote control of speed limits, heavy vehicles banning, etc. Taking into account that about 75% of the receivers living close by the road networks are impacted by noise levels that do not exceed noise limits for more than 3 dB(A), mitigation measures based on ITS could be effectively used to bring sound pressure levels below the noise threshold. A noise reduction of 2-3 dB(A) can be expected when interfacing the Dynamap System with appropriate ITS systems.

Furthermore, the development of a user-friendly tool to inform the public about noise pollution and other environmental issues will help to deliver simplified and easy to read noise maps according to END specifications.

From a social and environmental perspective, the Dynamap system will finally concur to reduce the sites to be noise mapped with traditional tools and expensive monitoring campaigns to collect input data, now limited to new or changed residential areas, as well as to provide a more comprehensive and reliable information on the environmental impact due to traffic, based on the number and type of additional sensors used to monitor the road network.

2.4 The project structure

The project structure is composed of four main steps:

1. Development of low cost sensors and tools for the management, processing and reporting of real time noise maps on a GIS platform.
2. Design and implementation of two demonstrative systems in the cities of Milan and Rome.
3. Systems monitoring for at least one year to check criticalities, analyze problems and faults that might occur over the test period. Test results are foreseen to be used to suggest system upgrade and to extend its implementation to other environmental parameters.
4. Preparation of a guideline for the design and implementation of real time noise maps.

The four steps are implemented through 14 main actions (Fig. 2):

- 2 preparatory actions to collect information on the state of the art of real time noise mapping, analyze the road networks and find areas to be used for implementing the demonstrative systems, acquire information on the pilot areas.
- 9 implementation actions to size the monitoring network, develop hardware and software, implement and test the system in the pilot areas, draft a guideline to real time noise mapping.
- 3 monitoring actions to assess public response and user ability in consulting and managing the system, evaluate costs and benefits, provide future visions on system applications.

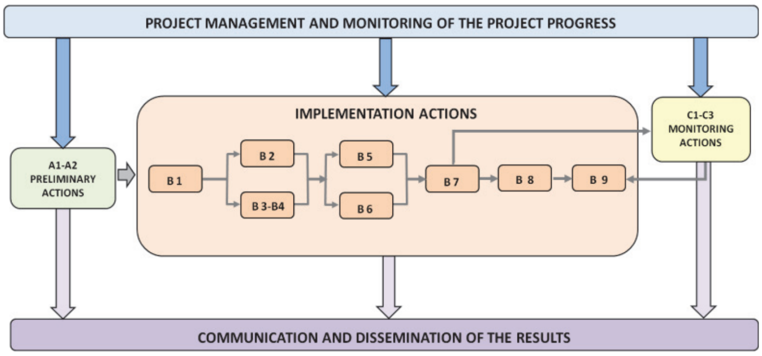


Figure 1 – Main project actions

3. PROGRESS OF THE PROJECT AFTER TWO YEARS WORKING

The project is currently approaching the implementation step, after two years of technological development and design of the system configuration.

The design of the system entailed the study of procedures to optimize the number and type of sensors needed to update the noise maps. This study also involved the identification of the basic noise maps to be prepared as a function of the parameters influencing noise emission and propagation. These specifications are closely linked to ambient features, thus different studies were carried out to configure the system in the two pilot areas.

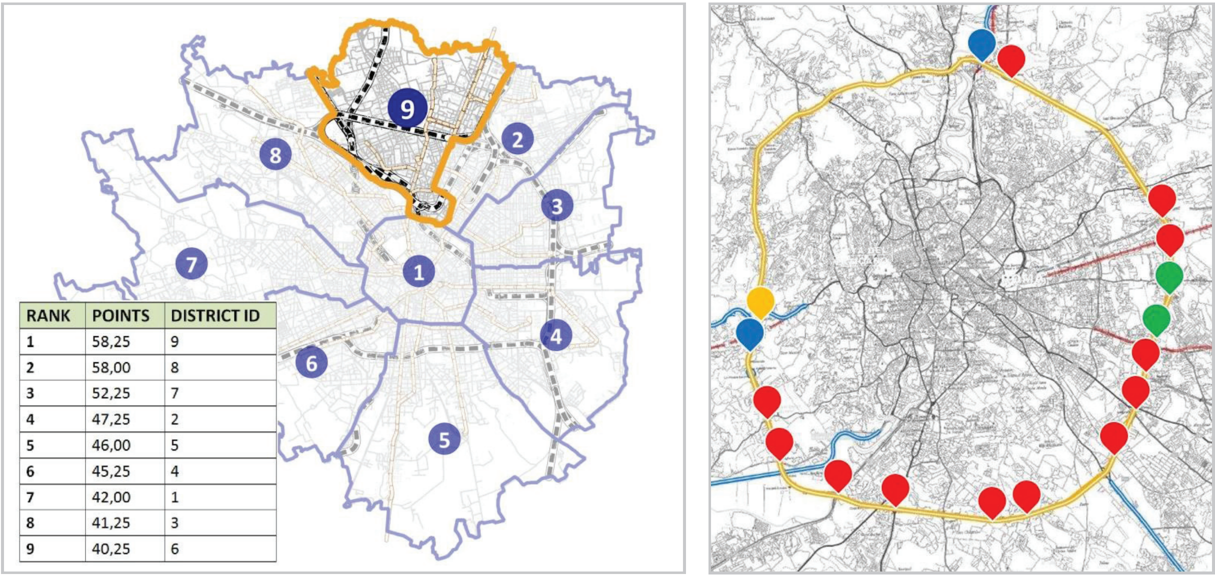
Preliminary actions were also accomplished at the start of the project to collect information on the state of the art of dynamic noise mapping and to locate the sites where the demonstrative systems will be installed. The latter led to the identification of two areas with different territorial and environmental characteristics located, respectively, in the agglomeration of Milan and along a major road, i.e. the ring road (Motorway A90) encircling the city of Rome.

3.1 Identification of the two pilot areas

The selection of the pilot areas was achieved using an automatic procedure specifically developed for the project. The selection process was based on a ranking system, whose scores were given as a function of a series of descriptive attributes related to territorial, mobility and functional features (power grid connections, communication networks, existing environmental and meteorological monitoring stations), noise levels, people and building exposed to noise, population density.

In the agglomeration of Milan, the procedure was applied to the nine administrative districts in which the city is broken down. At the end of the selection process district nine emerged as the best area to test the system. District nine is located in the northern part of Milan and has a population of about 180.000 residents, with 40.000 citizens exposed to L_{den} values exceeding 70dB(A).

In the pilot area of Rome, the selection process was applied to the 67 critical areas that were identified in the action plan of ANAS, the Italian Road Administration, within the first and second cycle of END. The selection process led to the identification of 17 critical sites representative of the main acoustic and environmental suburban scenarios, with single or multiple noise sources, such as railways, crossing and parallel roads.



RANK	POINTS	DISTRICT ID
1	58,25	9
2	58,00	8
3	52,25	7
4	47,25	2
5	46,00	5
6	45,25	4
7	42,00	1
8	41,25	3
9	40,25	6

Figure 3 –. The pilot areas of Milan (on the left) and Rome (on the right)

3.2 System design

The design phase of the project was accomplished through three main steps:

1. the definition of the system specifications;
2. the identification and optimization of the number of sites to be monitored for the calibration and update of the noise model;
3. the development of hardware and software components.

In the following paragraphs a summary of the work done and of the results achieved so far is described.

3.2.1 Definition of the system specifications

The identification of the system specifications was achieved as a result of discussions undertaken in the framework of meetings and public events arranged during the first working year.

Two different versions of the system have been defined (see figure 4):

- a *basic version*, performing only dynamic noise maps and public information;
- an *extended version*, performing dynamic environmental maps, that include, in addition to noise indicators, also other environmental parameters, such as weather conditions, air quality and traffic information.

In the basic version of the system the number of information neeeded depends on the variables affecting noise emission and propagation. These mainly deal with traffic and weather conditions. For different combinations of traffic and weather conditions, appropriate basic noise maps are foreseen and updated as a function of the noise level measured in the mapping area in real time.

In general, inside urban areas, meteorological data can be neglected as they don’t affect sound propagation conditions. On the contrary, in suburban areas, where the distance between the noise source and receivers can’t be ignored, this information is necessary to determine whether meteorological conditions are favorable, homogeneous or unfavorable to noise propagation and choose the appropriate basic noise map.

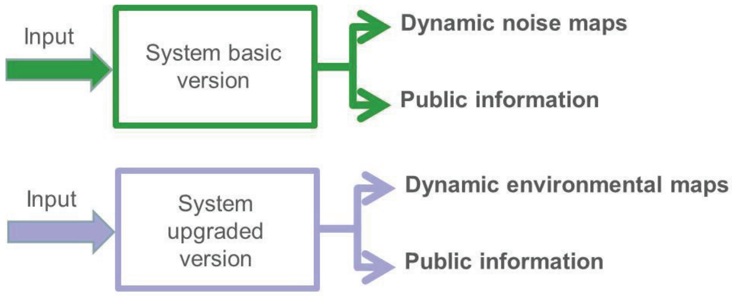


Figure 4 – Main features of the Dynamap system, in the basic version and in the extended version

As a consequence, the basic version of the system should be fed at least by a series environmental data, as shown in figure 5.

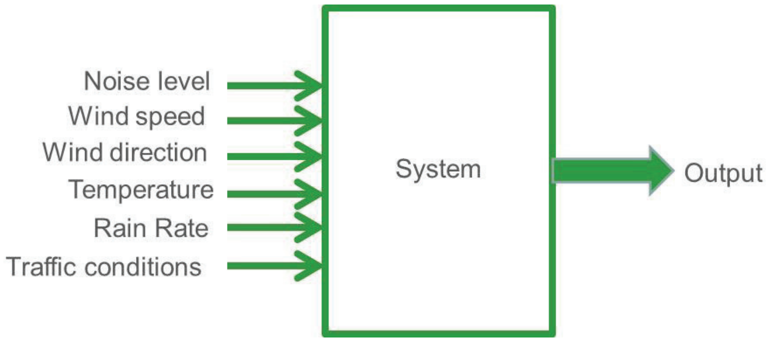


Figure 5 – Basic version of the Dynamap system

To provide such information, data should be measured by appropriate sensors or retrieved from existing monitoring devices, such as weather stations and traffic counters. As one of the main goal of the project is to provide a low cost system, data should be preferably gathered from existing, reliable monitoring stations in the immediate surroundings of the site to be mapped with a time frequency of at least 1 hour. In order to check the reliability of web information, the pilot areas will be equipped with additional stand-alone weather stations.

As for traffic conditions, data could be retrieved from the web (floating car data) or from local counter devices. Such information is necessary only in urban environment, as in suburban contexts the update of noise maps is performed using the noise levels detected by the monitoring stations. As a consequence, in this case traffic information will be reported only in the extended version of the system as additional data.

In terms of outputs, the basic version of the system should provide dynamic noise maps, statistical parameters and public information. As noise maps should comply with END and national specifications, they should provide a set of information useful to fulfill such requirements. This implies that noise levels should be updated not only on a grid, but also at receiver points. To accomplish this task, also the updated values calculated on the most exposed façade should be reported in a suitable format, as shown as an example in figure 6.

Statistical parameters, such as annual L_{den} data, people and dwellings exposed to noise level intervals and conflict values will be also provided off line to comply with END requirements.

In the extended version of the system, other inputs will be provided, such as air pollutant concentrations, traffic speed and volume to yield the following additional outputs: weather conditions, air quality and traffic information (see figure 7).

The extended version of the system also foresees the generation of alert signals in case of noise levels exceeding a fixed threshold and the provision of warning message to be displayed on Traffic Variable Message Signs to suggest less aggressive driving styles and lower speeds.

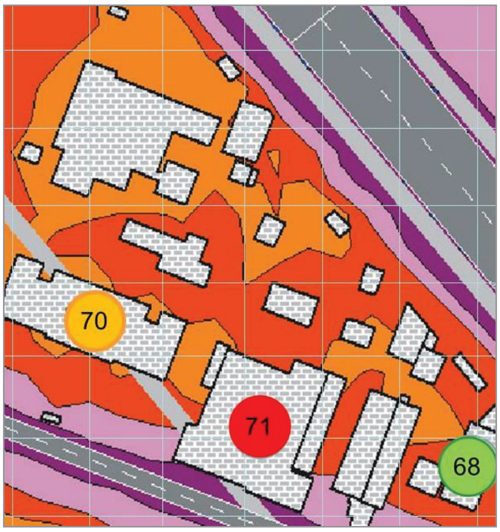


Figure 6 – A first example of the update of a noise maps on a grid and on the most exposed façade

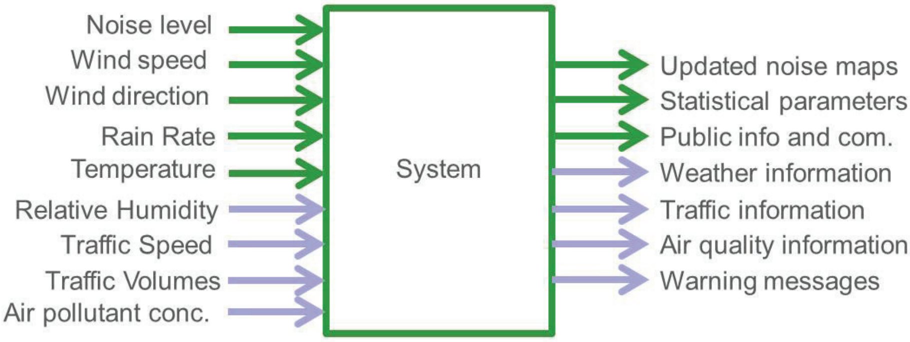


Figure 7 – Extended version of the Dynamap system

3.2.2 Sizing the monitoring network

Two separate studies were accomplished to design and set the configuration of the system in the two pilot areas, since different environmental impacts and characteristics can be ascribed to road noise inside and outside agglomerations.

The pilot area of Milan

Given the large number of roads present inside the city of Milan, a statistical approach was applied to size the monitoring network. Thus, roads having similar traffic flow conditions and, consequently, similar noise trends were grouped together after an extensive measurement campaign that involved the acquisition of daytime and nighttime noise levels from 93 monitoring stations distributed all over the city. The data achieved from the monitoring campaign were then analyzed and two main clusters with different noise trends and traffic flow were identified (see figure 8)(7).

In order to estimate the noise behavior of the unmonitored roads, a statistical model, based on traffic features, was finally implemented. In this model the estimate of the noise level is given by a linear combination of two quantities, named δ1(h) and δ2(h), i.e. the normalized mean hourly noise values related to clusters 1 and 2:

$$\delta i(h) = \beta 1\ \delta 1(h) + \beta 2\ \delta 2(h) \tag{1}$$

where $\beta 1$ and $\beta 2$ are weighting factors calculated as a function of a traffic parameter (X):

$$\beta 1 = P1(Xi) \,/\, (P1(X1) + P2(Xi)) \tag{2}$$

$$\beta 2 = P2(Xi) \,/\, (P1(X1) + P2(Xi)) \tag{3}$$

X is the logarithm of the total daily traffic flow (X=LogTT) and *P1(x)* and *P2(x)* are the distribution functions of *X* related to the two clusters. Therefore, the weighting factors $\beta 1$ and $\beta 2$ provide an estimate of the probability of a road stretch to be part of cluster 1 and 2.

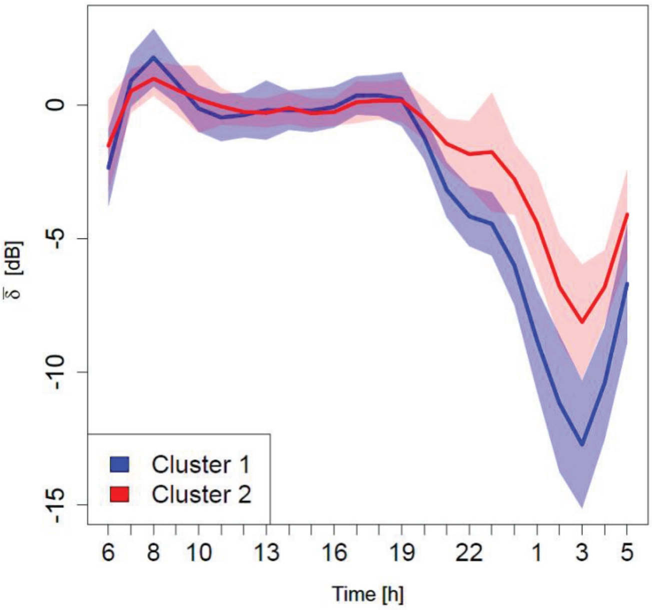


Figure 8 – Mean normalized noise cluster profiles and the corresponding standard deviation band

In order to define the number of basic noise maps to be prepared and of the monitoring stations to be installed, the parameter *X* was further analyzed with the aim to split the total range of *X* values in a reasonable number of groups with similar traffic characteristics. In the end, a total of six groups was found. Each group includes more or less the same number of roads and identifies the corresponding basic noise map. For each group, the mean value of *X* was also calculated, together with the weighting factors $\beta 1$ and $\beta 2$. These parameters were then used to determine the reference noise level of each group, to be updated in real time as a function of the sound pressure level detected on site by the monitoring stations, placed on locations having an hourly traffic flow similar to the mean value of each group. Four monitoring stations were identified for each group, leading to a total of 24 measurement points.

In order to keep the error of the noise level estimate roughly the same (i.e. around 2 dB), the updating of the noise maps was fixed with a different time frequency as a function of the day period: 5 minutes from 7 to 21 hours, 15 minutes from 21 to 01 hours and 60 minutes from 01 to 07 hours (6).

The pilot area of Rome

In the pilot area of Rome the design and configuration of the system are influenced by two main critical issues: the presence of additional noise sources and the effect of meteorological conditions on sound propagation (5).

As for the first issue, according to END separate acoustic maps should be prepared for different noise sources, therefore suitable sites should be identified to place the sensors and smart correlation factors between the main axis and its junctions should be defined, in order to reduce the number of independent elementary noise sources and of the related basic noise maps. To that end, an extensive monitoring campaign was arranged in order to assess the noise contribution of each source and provide an accurate model calibration. The acoustic characterization of the sources present in the pilot area was accomplished with an experimental methodology based on Kirchhoff's junction rule, using sound level meters and traffic counters. The outcomes of the monitoring campaign have shown that along the A90 motorway traffic flow is more or less equally distributed between the two carriages. It follows that noise levels can be detected on the main road axis without significantly affecting the accuracy of the acoustic maps, thus reducing the number of basic noise maps to be prepared and the sensors necessary to monitor the area. The number of basic noise maps was further optimized through the estimate of correlation factors between the noise levels generated by the main road axis and by the related junctions, leading to a total of 19 elementary noise sources.

As for the second issue, related to the influence of weather conditions on sound propagation, the attention was focused on finding a low cost suitable solution to retrieve or measure meteorological conditions, so as to define a reasonable number of propagation classes to be taken into account when preparing the basic noise maps. The criteria used to select the most appropriate solution were based not only on costs to gather meteorological data, but also on the time needed to process information and prepare the basic noise maps.

The results achieved from this study show that, on the basis of the main acoustic models currently available, only three propagation conditions can be simulated: homogeneous conditions, favorable or homogeneous conditions in specific wind sectors, favorable conditions in all directions. This assumption led to the main conclusion that detailed weather data are not necessary and that the information provided by only one meteorological station is sufficient to classify sound propagation conditions in the whole pilot area with an accuracy of 92%. Furthermore, the entire pilot area can be broken down into four wind sectors, thus reducing the variability of sound propagation conditions due to aerodynamic factors and the possibility of basic noise maps conflicts. This simplification allowed to cut down to six the number of basic noise maps needed for each independent elementary noise source: one for totally homogeneous conditions, one for totally favorable conditions and four for favorable conditions in wind sectors.

Since a different behavior of the elementary noise sources was observed in working and weekend days, two different basic noise maps must be prepared to reflect such difference for each propagation condition, one for working days and one for weekend days, leading to a total number of (2x6) = 12 basic noise maps.

3.2.3 Development of hardware and software components

The design of the system configuration proceeded in parallel with the development of hardware and software components, i.e. the low cost monitoring devices, the algorithm to detect and eliminate spurious noise events (ANED) and a web based GIS software application to update and report noise maps in real time.

Developing the low cost monitoring devices

One of the main goal of the Dynamap project is the development of low cost monitoring devices. In particular, the project includes the design of two sensor types:

- a high computation capacity sensor, able to perform many operations, included a spectral analysis of the detected signals, to be used in complex environmental contexts;
- a low computation capacity sensor, customized to perform a limited number of operations, to be used in simple suburban contexts, where detailed information on the noise spectrum is not necessary.

Both sensors are designed to gather, clean up and send data to a central server, where they are analyzed, processed and used to scale the basic noise maps. The clean-up function is achieved by means of an algorithm especially developed for the project, named ANED (Anomalous Noise Events Detection). The algorithm is embedded in the monitoring device, in order to obtain a more scalable and less complex system, thus avoiding the need for variable computational load as a function of the number of monitoring stations (8).

The cleaned up signals are averaged over a time period that depends on the context and might vary from a few seconds in suburban areas to 5-60 minutes in urban environment. This time period determines the update frequency of the noise maps.

Each monitoring station provides a classified output that is stored in a remote web server by means of wireless data communication systems (3G).

The high computation capacity monitoring stations are composed of low cost microphones and inexpensive embedded pc's, with high quality sound-boards and 3G modems. The main advantage of this system configuration relies on the possibility of being remotely fully updated and reprogrammed. The main disadvantage of this solution stands in its high power consumption (>2-3 W), that entails a physical connection to the electric power grid, limiting its application as a stand-alone system.

A different solution is under development for the low computation capacity sensors, in order to reduce costs and make them operating also off-line with solar panels and batteries.

Detecting anomalous noise events

Automating the update of road traffic noise maps through the DYNAMAP system entails several consequences. One of them has to do with the fact that noise levels captured and measured by the network of low cost sensors would be represented on the dynamic maps regardless of their origin. As consequence, the resulting maps would not constitute a faithful reflection of the acoustic impact of road infrastructures (8).

For this reason, it is necessary to endow the DYNAMAP system with the ability to discern between road traffic noise and other types of acoustic events (e.g., aircrafts, industries, works on the road, etc.), to exclude the latter from the noise level computation. To that end, an anomalous noise event detection (ANED) algorithm was developed. This algorithm operates on the audio stream captured by the acoustic sensors and identifies the presence of acoustic events unrelated to road traffic, activating an alert signal to exclude the corresponding audio passages from the computation of noise levels.

The design of the ANED algorithm follows a “detection-by-classification” approach, consisting in the binary classification of sequential audio segments as either “road traffic noise” or “anomalous noise event” (9). Based on semi-supervised machine learning, its architecture is depicted in figure 9 (10).

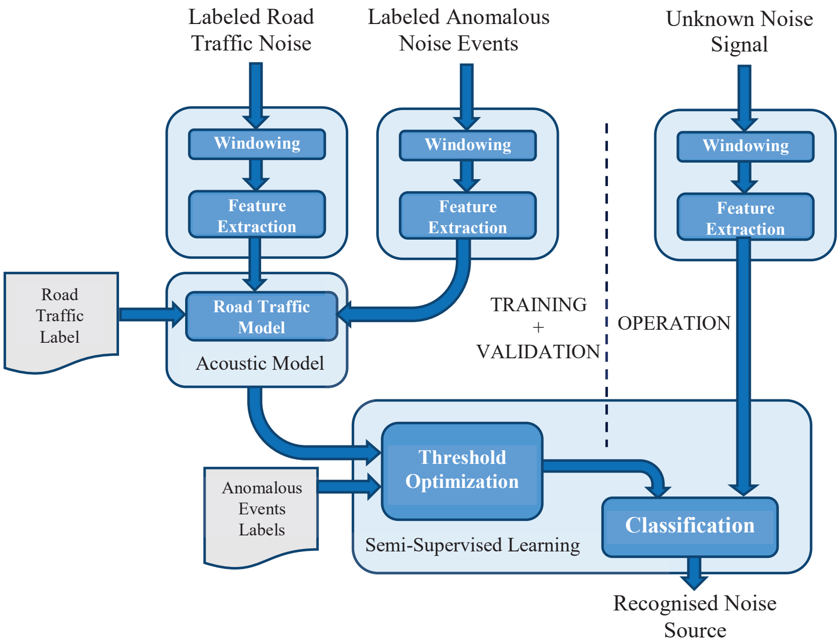


Figure 9 – Block diagram of the anomalous noise event detection algorithm (10)

The algorithm is able to discern three main signal categories: road traffic noise, background city noise, and anomalous events. This latter class is further subdivided into 18 subtypes of events, such as people talking, music in car or in the street, or noise caused by tramways or trains, among others.

The ANED algorithm was trained, validated and tested using a data set containing samples of both road traffic and anomalous noise events achieved from an environmental noise recording campaign carried out within the two pilot areas of Rome and Milan (11).

Designing the GIS software application

The role of the GIS software application is to re-scale pre-computed partial noise maps, i.e. the basic noise maps, related to each noise source as a function of the noise levels detected by the monitoring devices, sum them together in order to achieve the updated noise map of the whole area and finally publish the results on a web site (8). As a matter of fact, the system performs several tasks simultaneously: data collection and storage, maps scaling and sum, public information on the web. This implies the design of a complex data-base structure and of a bi-directional communication system between the monitoring devices and the data collection unit (12).

As noise maps should comply with END and national specifications, the software must also provide, in addition to dynamic noise maps, a series of statistical information useful to fulfill such requirements, such as day, evening and night data, L_{den} data, people and dwellings exposed to noise level intervals, etc. However, only hourly data will be stored, while the statistical parameters will be calculated off line when needed.

As for public information and communication, two levels for accessing the system have been foreseen:

- *a high privilege access level,* reserved to authorized stakeholders only, that allows to reach detailed information, such as time histories and statistics.
- *a low privilege access level*, fully open, to inform about noise levels impacting the mapped areas and ease the participation of the public in the preparation of action plans.

Public information will include dynamic noise maps, weekly (day and night) maps, limit and conflict values, communication tools and general educational information on noise issues and driving style suggestions to reduce the noise impact on the environment.

4. CONCLUSIONS

The Dynamap project is a five years long project, aimed at developing a dynamic noise mapping system, able to detect and represent in real time the acoustic impact of road infrastructures. The project involves the development of low cost sensors and tools for the management, processing and reporting of real time noise maps and the design and implementation of two demonstrative systems in the cities of Milan and Rome.

After two years working, focused on the design of the system and the development of hardware and software components, many interesting results have been achieved in the effort to simplify the system and reduce its cost as much as possible. These include, among the others, the preparation of statistical models to size the monitoring network in urban and suburban environments, the identification and definition of the method to be used to update the noise maps in real time, the design of low cost monitoring sensors, the implementation of algorithms to remove anomalous events from the noise level, the development of software applications to scale and sum the basic noise maps, provide statistical information and ease the participation of the public in the preparation of the action plans.

The project is now approaching the next experimental phase where the first prototype of the Dynamap System will be installed and tested. A one-year survey has been envisaged to check the reliability, effectiveness and efficiency of the system. Test results will then be used to fine-tune and upgrade the system, as well as to extend its implementation to other environmental parameters.

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