24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

LIFE DYNAMAP: THE REAL TIME MAPPING SYSTEM COMES TO LIFE

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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. To that end, an automatic monitoring system, based on customized low-cost sensors and a software tool implemented in a general purpose GIS platform, was 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 three years working, focused on the design of the system, the development of hardware and software components and the construction of the test sites, the project partners are now involved in the next experimental phase, where the Dynamap System reliability, effectiveness and efficiency will be evaluated. 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 mapping, real time monitoring.

1. Introduction

The DYNAMAP project (Dynamic Acoustic Mapping - Development of low cost sensors networks for real time noise mapping) is a LIFE project aimed to develop a dynamic noise mapping system able to detect and represent in real time the acoustic impact of 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. However, 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, as it will be described in more detail in the following paragraphs.

2. The DYNAMAP project

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 Fig. 1 a schematic representation of the DYNAMAP system is shown.

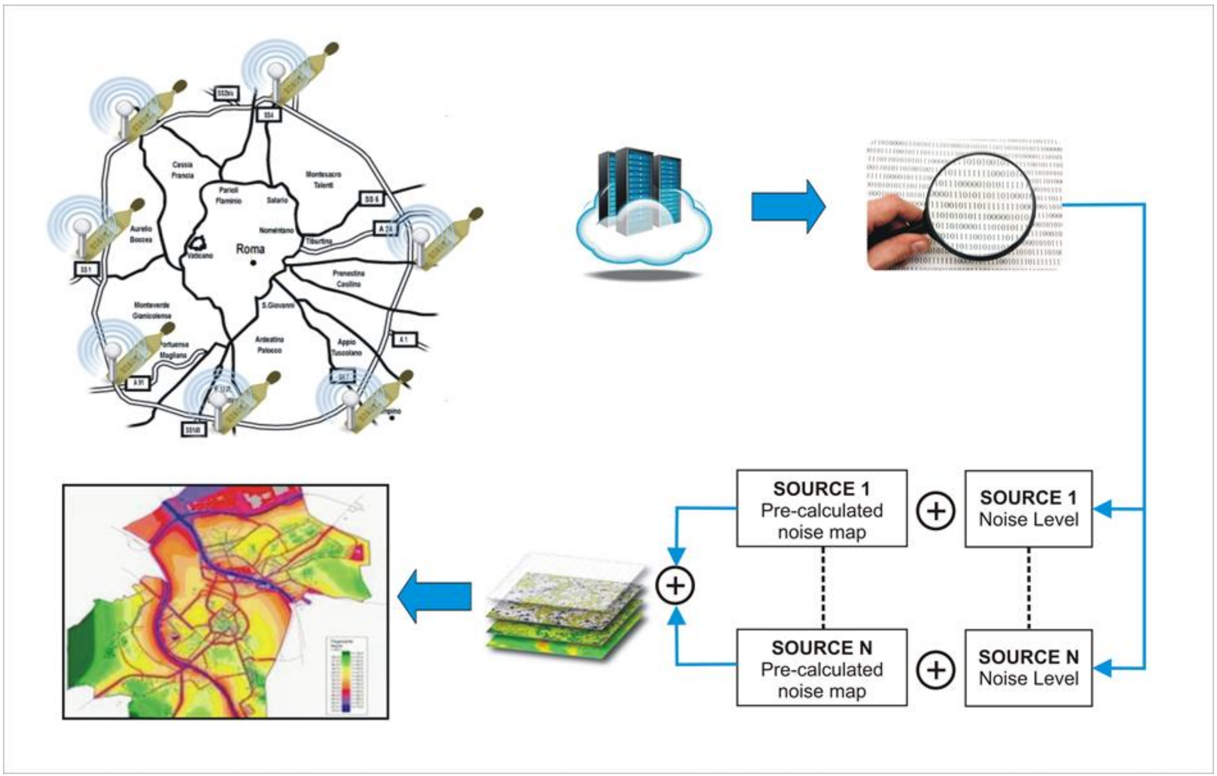
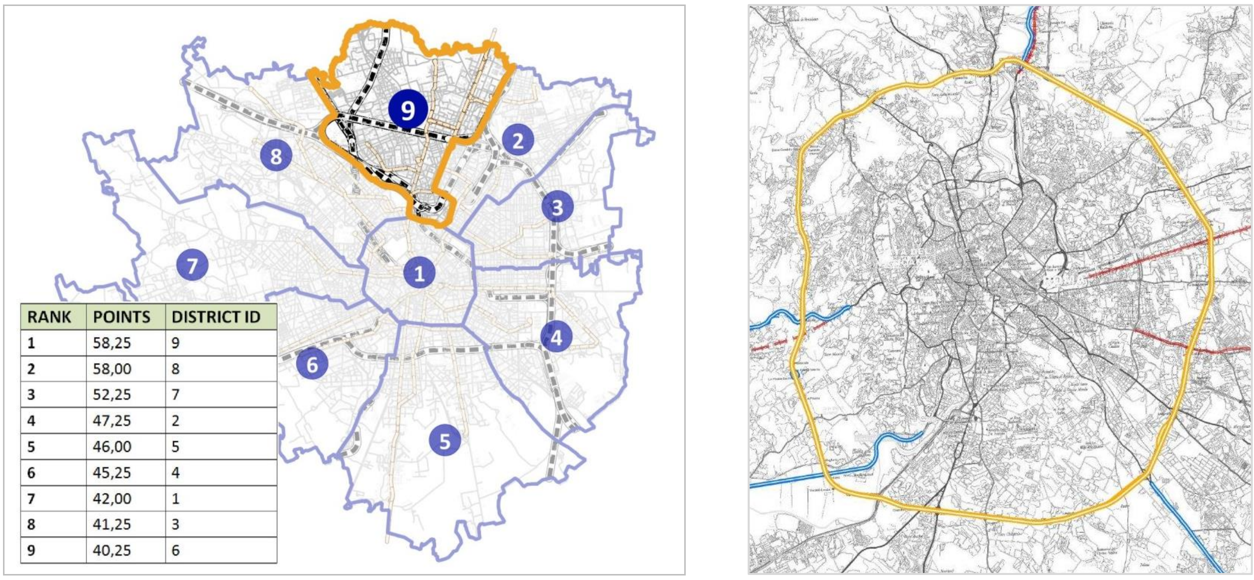


Figure 1 – Schematic representation of the DYNAMAP system

The feasibility of this approach will be proven implementing the system in two pilot areas with different territorial and environmental characteristics: an agglomeration and a major road. The first pilot area is located in the city of Milan, in the northern part of the town (district 9), where different type of roads and acoustical scenarios are present. The second pilot area is located along a major road, the motorway A90, that encircles the city of Rome (see Fig. 2).



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

The project has been broken down into 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 9 implementation actions focused on technical issues to size the monitoring network, develop hardware and software, implement and test the system in the pilot areas.

3. Progress of the project

The project is currently approaching the implementation step, after more than two years of technological development and design of the system configuration that involved:

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.

3.1 Definition of the system specifications

The identification of the system specifications was achieved as a result of discussions undertaken in meetings and public events that led to the definition of two different versions of the system (see Fig. 3):

- a *basic version*, performing only dynamic noise maps and public information;
- an *extended version*, performing dynamic environmental maps, that includes, 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 needed 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.

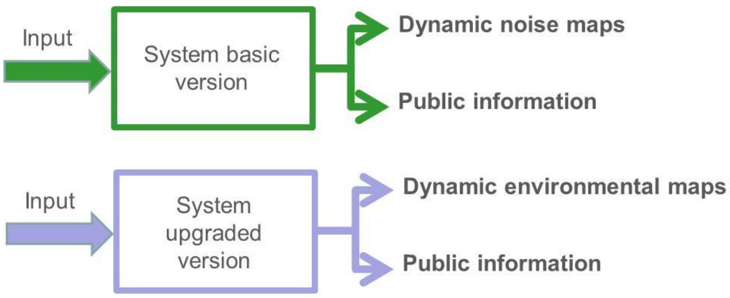


Figure 3 – Main features of the Dynamap system, in the basic version and in the extended version

To provide such information, data should be measured by appropriate sensors or retrieved from existing monitoring devices. As one of the main goals of the project is to provide a low cost system, data will be preferably gathered from existing, reliable monitoring stations in the immediate surroundings of the site to be mapped.

In terms of outputs, the basic version of the system will provide dynamic noise maps, statistical parameters and public information, according to END and national specifications. This implies that noise levels should be updated not only on a grid, but also at receiver points. Statistical parameters, such as annual L_{den} data, people and dwellings exposed to noise level intervals and conflict values will be made available off line.

In the extended version of the system, additional 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.

3.2 Design of the system configuration

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

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 Fig. 4).

In order to estimate the noise behavior of the unmonitored roads, a statistical model, based on traffic features, was finally implemented [5], [6]. 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 difference values related to clusters 1 and 2:

$$\delta i(h) = \beta 1\ \delta 1(h) + \beta 2\ \delta 2(h) \quad (1)$$

where *β1* and *β2* are weighting factors calculated as a function of a traffic parameter (X):

$$\beta 1 = P1(Xi) \,/\, (P1(X1)+P2(Xi)) \quad (2)$$
$$\beta 2 = P2(Xi) \,/\, (P1(X1)+P2(Xi)) \quad (3)$$

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 *β1* and *β2* provide an estimate of the probability of a road stretch to belong to cluster 1 and 2.

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 *β1* and *β2*. 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 [7].

In order to keep the error of the noise level estimate roughly the same (i.e. around 2 dB), the update of the noise maps will be delivered with a different time frequency as a function of the day period: 5 minutes from 7 a.m. to 9 p.m., 15 minutes from 9 p.m. to 1 a.m. and 60 minutes from 1 a.m. to 7 p.m. [5].

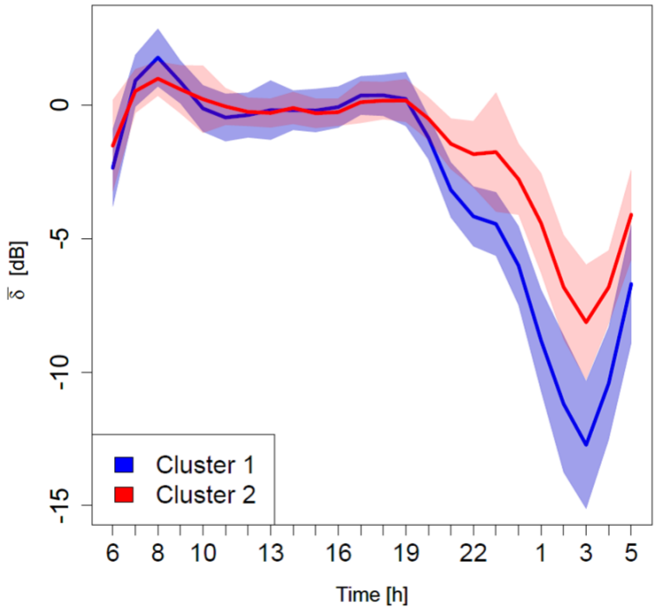


Figure 4 – Mean normalized noise cluster profiles and the corresponding standard deviation band [8].

In the pilot area of Rome the design and configuration of the system were influenced by two main critical issues: the presence of additional noise sources and the effect of meteorological conditions on sound propagation [9].

As for the first issue, according to END separate acoustic maps should be prepared for different noise sources, therefore in order to reduce the number of independent noise sources to be monitored and noise mapped, an extensive monitoring campaign was arranged to assess the contribution of each source to the overall noise level and provide an accurate model calibration. 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 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 specific wind sectors.

Since a different behavior of the elementary noise sources was observed in working and weekend days, two different basic noise maps were 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.

3.3 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-GIS software application to update and report noise maps in real time.

3.3.1 Designing the low cost monitoring devices

The development of the low cost monitoring devices involved the design of two sensor types:

- a high computation capacity sensor, able to perform many operations, including 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 [10].

The high computation capacity monitoring stations are composed of low cost microphones and inexpensive embedded electronic boards, with high sound quality 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.

3.3.2 Detecting anomalous noise events

Automating the update of noise maps through the DYNAMAP system entails several consequences. One of them deals with the content of the detected noise level, that can include, in addition to the main noise source, i.e. the road traffic, the contribution of other noise sources present in the mapping area. As a consequence, the resulting maps would not constitute a faithful reflection of the acoustic impact of road infrastructures [10].

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” [10], [11].

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

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 in the two pilot areas of Rome and Milan [11].

3.3.3 Developing 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. 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.

As noise maps should comply with END and national specifications, the software provides also, 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.

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

- *a high privilege access level,* reserved to authorized stakeholders, 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.

4. Implementing the Dynamap System in the two pilot areas

At the end of the design of the system configuration six groups of roads with similar traffic features and noise trends were found in the pilot area of Milan. Four monitoring devices were foreseen to be installed for each group of roads, leading to a total of 24 monitoring stations. The noise signal detected by these monitoring devices will be used to update the basic noise maps. One basic noise map for each group of roads.

In the pilot area of Rome the road network was broken down into 19 elementary noise sources, corresponding to as many road stretches with invariant traffic trends. In this case 19 high computation capacity sensors (HCCS) will be installed at the top of portals located along the motorway. Four low computation capacity sensors (LCCS) are also foreseen to be placed in parallel with the HCCS to check their ability in the detection and removal of anomalous noise events. The noise levels detected by these monitoring devices will be used to update the most appropriate basic noise maps among those prepared for the area. Since the selection of the basic noise maps depends on traffic and sound propagation conditions, 4 weather stations will be also installed to complete the system configuration. The weather stations will be placed in positions corresponding to the main four wind sectors (north, south, east and west). In Fig. 6 a picture of the devices built for the pilot area of Rome and a map of the sites where the devices will be installed are shown. Installations are foreseen to be completed by the end of April 2017.

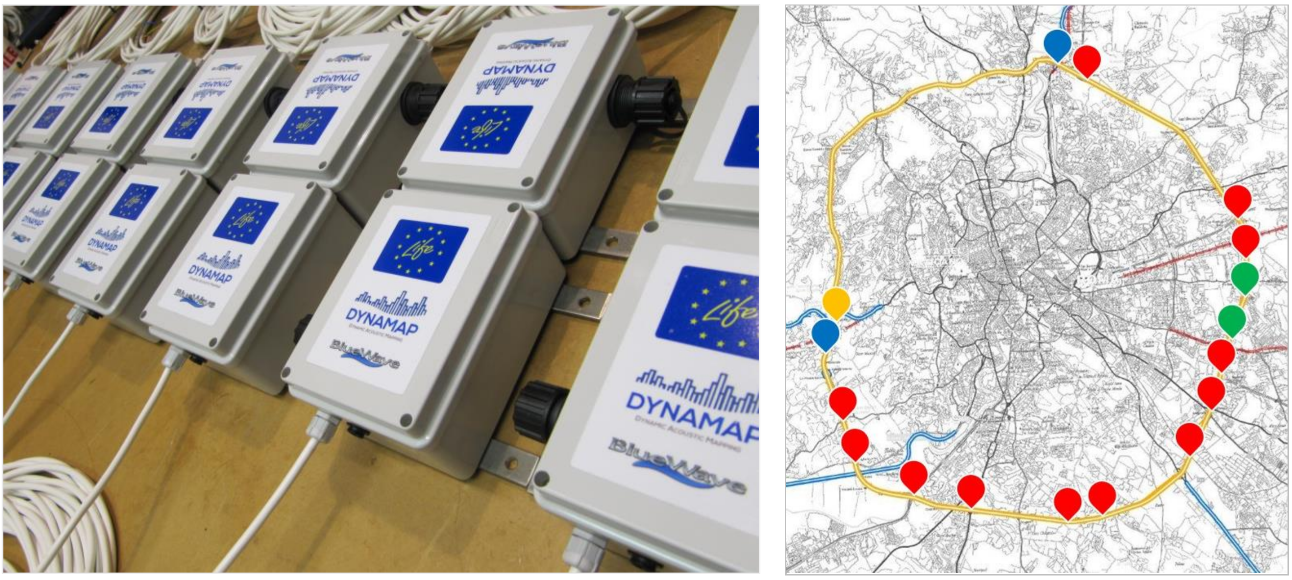


Figure 6 – The 19 HCCS built for the pilot area of Rome (on the left) and a map of the positions where the devices will be installed (on the right)

The two demonstrative systems will be tested for at least one year to check their reliability, effectiveness and efficiency. The test results will be then used to fine-tuned and upgrade the system, as well as to extend its implementation to other environmental parameters [12].

5. Discussion and 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 more than 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.

6. Acknowledgements

This research has been partially funded by the European Commission under project LIFE13 ENV/IT/001254 DYNAMAP.

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