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Initial verification of Dynamic Acoustic Mapping along the motorway surrounding the city of Rome

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ABSTRACT

DYNAMAP (Dynamic Acoustic Mapping) is a EU LIFE project which aims at developing a dynamic noise mapping system in urban areas (Milan city) and along the motorway A90 surrounding the city of Rome. The two pilot areas present very different characteristics such as the presence of multiple noise sources, roads junctions, traffic and weather conditions that require different approaches and solutions. This work summarizes the main progresses achieved in noise mapping operations in the city of Rome, its criticalities and ongoing proposed solutions regarding the treatment of Anomalous Noise Events detection unrelated to vehicle traffic sources.

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1 INTRODUCTION

The LIFE DYNAMAP project is EU co-founded research aimed at developing real time noise maps using low cost sensors and a general purpose GIS platform. This project is developed in the framework the European Directive 2002/49/EC (END) [1] related to the assessment and management of environmental noise. In particular, it refers to the need for noise maps to be updated every five years, as stated in the END. However, this process is usually time consuming and has a significant impact on the financial resources of municipal authorities. In order to reduce the economic impact, noise mapping can be automated by developing an integrated system for data acquisition and processing, able to detect and report in real time the acoustic impact of noise sources. The proposed system makes use of low cost sensors, installed at relevant receivers locations, measuring the sound pressure levels emitted by the primary noise sources and of a software tool based on a GIS platform able to perform real-time noise maps. The noise map update is obtained by scaling pre-calculated basic noise maps, prepared for different sources, traffic and weather conditions. A complete basic noise map covering the entire mapping 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.

Dynamap is being developed in two pilot areas with different territorial and environmental characteristics: an urban area, i.e. the city of Milan and along the motorway A90 surrounding the city of Rome. Different studies were carried out to analyze at large the two pilot areas. In Milan, a statistical approach has been performed based on the observation that roads which display similar traffic noise behavior can be clustered into a single noise map behavior [2-6]. From the analysis, we developed a model for predicting the traffic noise behavior of an arbitrary road stretch within the same area whose real-time variations are continuously updated recording the traffic noise from a small number of monitoring stations distributed over the urban zone of interest.

The pilot area of Rome is located along the 68 km long A90 motorway surrounding the city. Critical areas are characterized by the presence of single or multiple noise sources, such as railways, crossing and parallel roads and the influence of meteorological conditions when dealing with sound propagation [7]. The first issue needs to differentiate the noise level generated by the primary source from the contributions of other noise sources included in the mapping area, as required by the END. This is a tricky problem, as usually major roads go through suburban complex scenarios, where multiple connections to other transport infrastructures are present. Since noise maps should refer only to the primary source, the influence of other noise sources should be possibly removed. As for the second issue, noise levels at receivers also depend on weather conditions. For this reason, acoustic waves propagation should be taken into account, accordingly. This requires the monitoring of meteorological conditions and the conversion of this information into acoustic propagation classes.

This work summarizes the main progresses achieved in noise mapping operations in the city of Rome, its criticalities and ongoing proposed solutions regarding the treatment of Anomalous Noise Events detection unrelated to vehicle traffic sources.

2 TEST MEASUREMENT SET-UP AND RESULTS

Noise monitoring stations were installed on portals carrying Variable Message Panels (VMP). The choice was dictated by the easy access to the electric power grid (figure 1) and to prevent thefts. The microphone is placed between 50 and 200 cm from the panels.

Fig. 1 – Portals carrying Variable Message Panels (VMP) with the installed sensor.

In order to evaluate the monitoring stations' accuracy, we performed 5 measurements using class I phono-meters. Each portal corresponds to a different type of installation dictated by the specific hosting structure. For safety reasons, we performed a 10 minutes measurement by means of a Synphonie Instrument in order to make an on-site "calibration" measurement of Dynamap in position (1) and Synphonie sensor in position (2) of figure 2. Note that the sensor in position (2) was held by hand.

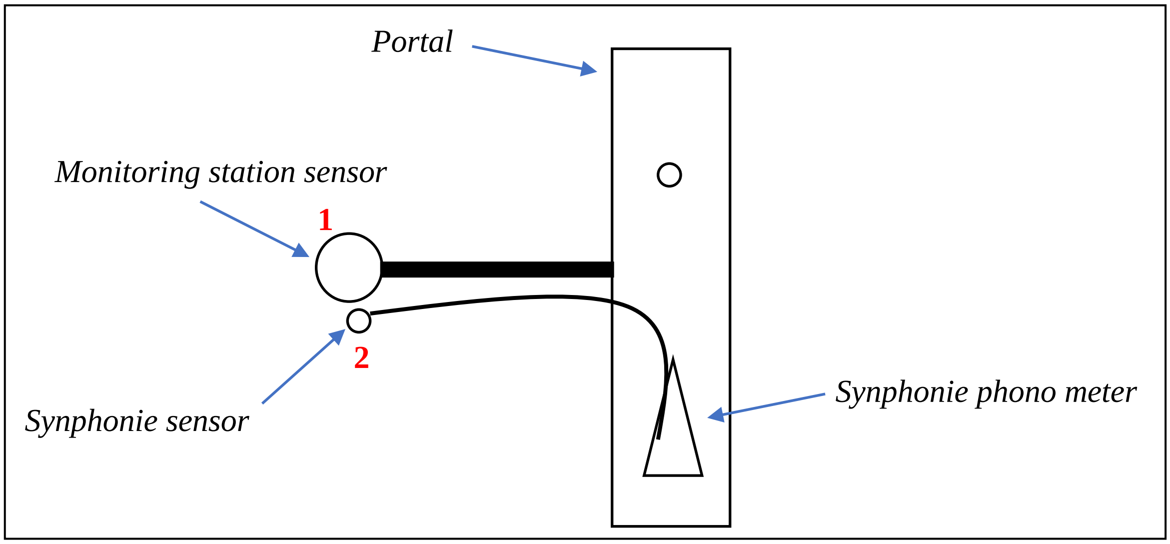


Fig. 2 – Scheme of on-site calibration measurements.

In figure 3, we report the correlations between Leq (10s) recorded simultaneously by the sensors over a period of 10 minutes. The mean deviation between the two sensors resulted 1.0 ± 0.4 dB.

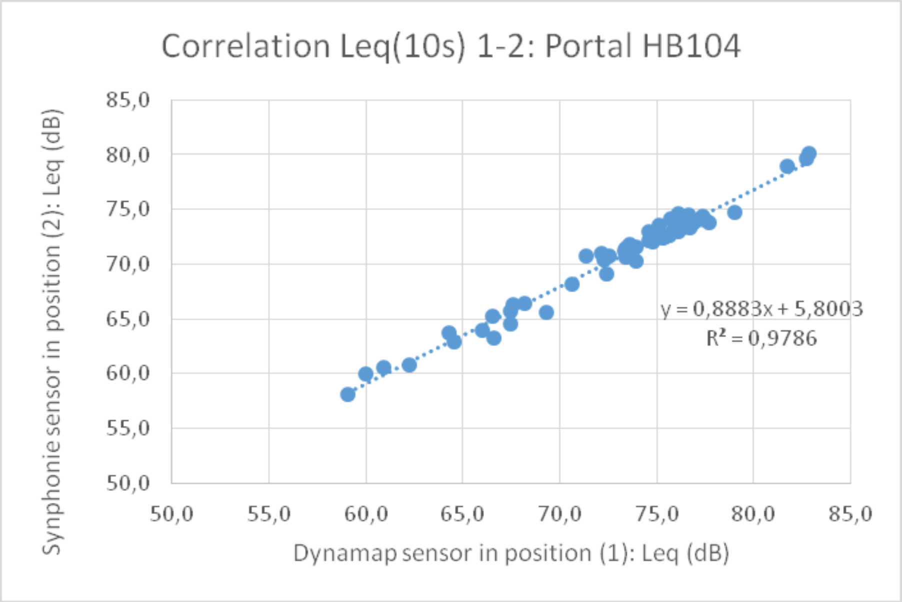


Fig. 3 – Calibration measurements between Synphonie and Dynamap sensors performed according to the scheme of figure 2 for portal hb104.

3 CUSTOMIZED ANOMALOUS EVENTS MODEL DETECTION

The Anomalous Noise Event Detector (ANED) has been conceived as a two-class classifier that labels input audio signals between two acoustic categories [8]: Road Traffic Noise (RTN) and Anomalous Noise Events (ANE), which is any noise event non-related to traffic (e.g. sirens, horns, birdsongs, etc.). The classification system consists of an audio parameterization stage that represents each audio frame of 30 ms by a set of cepstral-based coefficients followed by a binary classifier that follows a two-level decision scheme: making an RTN/ANE decision per frame, and subsequently integrating them every second. The original implementation of the ANED [8] to run in real time on a low-cost acoustic sensor is currently being redesigned to take into account the new context of operation after the deployment of the Wireless Acoustic Sensor Network (WASN) in the two pilot areas of Milan and Rome. Some previous studies were carried out using audio samples gathered in similar locations where the sensors were to be finally placed [8, 9]. The audio database that was used for this preliminary ANED validation (here named as *preliminary* audio database) contained samples from two types of environments (urban and suburban). In the suburban scenario of the Rome ring, a labelled database composed up to 4 hour and 44 minutes of RTN and ANE was generated. The total amount of ANEs was about 3.3% of the total recorded time [10]. However, the Rome recordings was supposed to model daytime noise patterns, and were obtained during two working days. The analysis showed that the most relevant ANEs were attributed to sirens and vehicle horns [11].

In the aim of adapting the ANED to the characteristics of the final WASN, audio data obtained from Dynamap acoustic sensors from the network has been considered. The Dynamap sensors of the network (figure 4) allow high computational capacity and are able to discard the ANE from the RTN in real time. It is important to highlight that the recording conditions have been changed with regard the preliminary recording campaign, not only by the fact that more recording locations have been added but also because the exact placement of the sensors within the highway portals are different, e.g. the sensor is placed closer to the pavement so also to the sound sources.

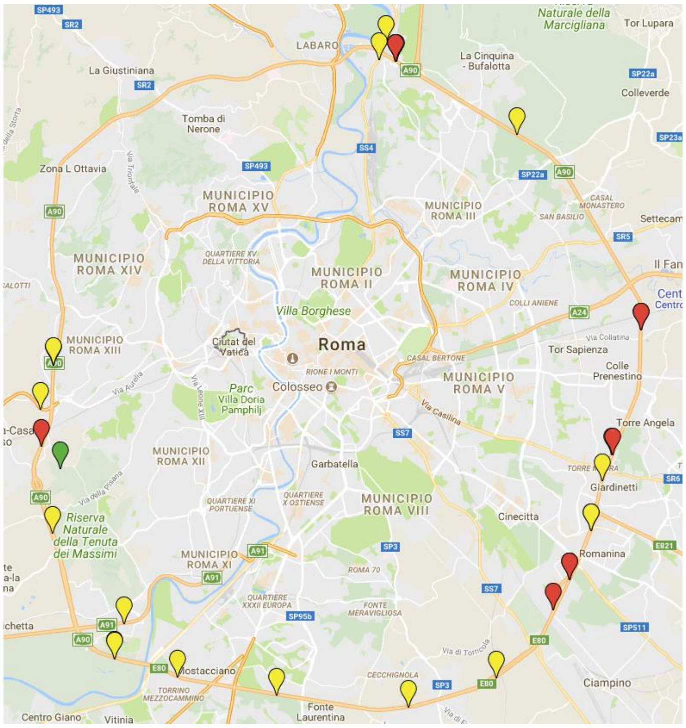
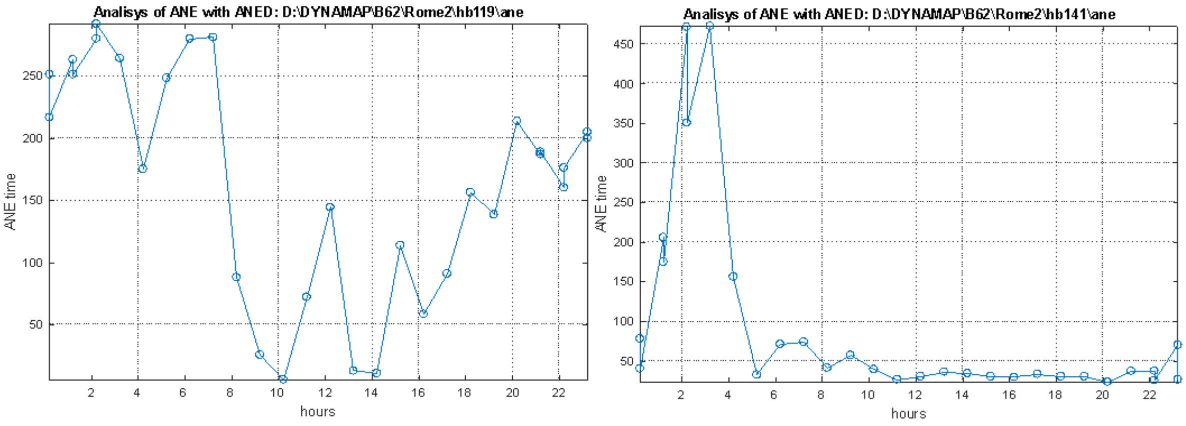


Fig. 4 – Map of the sensors location for the DYNAMAP project in the pilot area of Rome (the colors of the various locations represent different structural types of motorway A90: critical areas, complex critical areas with multiple connections, with railways, parallel roads in crossing).

A study was performed using new audio data recordings in five locations out of 19 final sensor locations, i.e. those locations that were considered during the preliminary audio database and that coincide with the definitive sensors placements. Two days were recorded (one working day and one weekend day) at a regular basis of 20 minutes per hour, 24 hours a day. The WASN recorded both one raw audio file and the correspondent ANED decisions, previously trained with the preliminary acoustic dataset. The purpose of this experiment was studying to what extent the preliminary ANED version was able to generalize to the new context. For data gathering, we could collect new recordings to check results. From the result analysis, it was concluded that the preliminary ANED obtained a poor classification performance, which was especially critical during night periods, when too many ANE false alarms of were produced. In Figure 5 an example of the total ANE duration obtained by the ANED output per hour is depicted for two different sensors during a working day, where it can be seen that too many ANEs are detected between 00:00 and 05:00, especially for the sensor hb141 (b). In addition, the first plot of figure 5 (a) shows also many ANEs detected during the rest of the day. After checking that the ANED did not reach the same accuracy as in the tests with the preliminary dataset, we observed that the road traffic noise during night periods were different from the noise profiles during daily recordings of the preliminary database. Moreover, the hypothesis about the detection errors found during daytime can be attributed to differences in the recording conditions (e.g. sensors placement), but this stage will be studied deeply in the future.



(a)

(b)

Fig. 5 – Analysis of the ANED performance in terms of total ANE time for the sensors hb119 (a) and hb141 (b) during a working day (02-11-2017).

We have discarded the data from the preliminary dataset and trained the ANED to deploy in the WASN with the 19-sensor final location labelled data. To this purpose, a new set of recordings were produced from the complete set of 19 Hi-Cap sensors of the WASN, following the same approach: two types of days (one working day and one weekend day), the same sampling of 20-mins 24-hours. Moreover, during the weekend day, an episode of rain was observed, which allowed enriching the new database with diverse meteorological conditions that could affect road traffic noise profiles. Audio data labelling was conducted in 50% of the available audio files (performed for odd hours) by subjective listening and by five trained listeners; for more details, see [12]. The labelling consisted of marking the ANE time regions and discarding the time regions where it was difficult to take a reliable decision (regions marked as complex regions). In addition, log-based spectrograms and preliminary ANED output decisions were used as references to ease the labelling process. This process led us to observe more types of ANE than in the preliminary audio database: birdsongs (especially with an important impact when a bird approached the sensor), sounds of machinery from neighboring industries (with more salience during night periods), and heavy rain (that was considered as ANE when masked the background road traffic noise).

The recording campaign performed within the WASN produced as output a total of 107 hours and 12 minutes of labelled audio. With 2.52% of ANEs and 97.43% of RTN, it maintains the ratio of the preliminary dataset. Future work will exploit all these new data to retrain and validate the ANED and finally ensure its proper operation within the whole acoustic sensor network.

4 DYNAMIC NOISE MAP VALIDATION

In the pilot area of Rome dynamic noise maps are achieved by scaling pre-calculated noise maps (basic noise maps), prepared for different traffic and weather conditions, as a function of the noise levels detected by the monitoring stations and of meteorological data published on the web.

A basic noise map is a map that reports for each point of the grid the contribution of the independent noise sources present in the mapping area, namely road stretches with different traffic features. After an accurate measurement campaign to assess the contribution of each source to the overall noise level, 19 elementary noise sources have been identified. For each elementary noise source 6 propagation conditions and 2 traffic distributions (one for working days and one for weekend days) have been defined, leading to a total of (2x6) = 12 basic noise maps.

4.1 Basic noise maps

From the modeling perspective, a basic noise map is an array that includes the contribution of the elementary noise sources present in the mapping area for each point of the grid.
The array reports on each row the contribution of the whole set of elementary noise sources to one point of the grid. So the first column contains the identification code of the grid point (ID), followed by its coordinates and the contribution of each elementary noise source. The last column reports the sum of the contributions related to that point, that is given by:

$$LeqR_j = 10\, log \sum_{j=1}^{N} 10^{0.1 Leq_{j,i}} \qquad (1)$$

where:

- R_j is the final equivalent noise level associated with the *j-th* grid point;
- $Leq_{j,i}$ *is* the equivalent noise level related to the *j-th* grid point and the *i-th* elementary noise source;
- N is the number of elementary noise sources.

Table 1 shows the structure of the array.

Table 1 - Structure of the basic noise map.

ID	**LAT**	**LONG**	**NS1 dB(A)**	**NS2 dB(A)**	**NS3 dB(A)**	**…**	**NSN dB(A)**	**Leq $_T$ dB(A)**
0001	X0001	Y0001	L_{11}	L_{12}	L_{13}	…	L_{1N}	Leq_{R1}
0002	X0002	Y0002	L_{21}	L_{22}	L_{23}	…	L_{2N}	Leq_{R2}
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
9999	X9999	Y9999	L_{99991}	L_{9992}	L_{99993}		L_{9999N}	Leq_{R9999}

Since each column refers to a single noise elementary source, the update of the array is made by scaling the data reported in columns on the basis of the noise level detected by the monitoring stations. The quantity to be scaled is given by the difference between the measured value and the calculated value in a reference point:

$$\Delta_i = measured\ value_i - L_{referencepoint_i,} \qquad (2)$$

The reference point corresponds to the position where the monitoring station is located.
An extra array has been prepared reporting the calculated noise levels of all reference points (see table 2).

Table 2 - Calculated noise levels at the reference points.

ID	LAT	LONG	H (m)	Leq dB(A)
Rif01	X0001	Y0001	H_1	Leq_1
Rif02	X0002	Y0002	H_2	Leq_2
…	…	…		…
…	…	…		…
…	…	…		…
RifN	X_N	Y_N	H_N	Leq_N

The same kind of approach is used for the identification of the maximum noise level and the most exposed façade at receiver locations. In this case the array reports the ID and position of the receiver, its height or floor, and the contribution of each elementary noise source, together with the overall noise level. The update of the noise level at receivers is achieved using the same approach described for the horizontal noise maps. Each column, corresponding to the contribution of the different noise sources, is updated as a function of the noise level detected by the monitoring stations.

4.2 Selection of the basic noise maps

As previously cited, six basic noise maps have been prepared to take into account sound propagation conditions. The selection of the appropriate array is accomplished by converting meteorological conditions into sound propagation conditions. Sound propagation conditions are determined according to the NMPB 2008/CNOSSOS model, where five classes of propagation conditions are defined, as shown in table 4.

Table 3 - Qualitative definition of average acoustic propagation classes.

Propagation class	Propagation conditions	Effect on the sound levels
M0	Very upward refraction	Extremely high attenuation and dispersion
M1	Upward refraction	High attenuation and dispersion
M2	Homogeneous	'Normal' propagation and dispersion
M3	Downward refraction	Major increase and moderate dispersion
M4	Very downward refraction	Extremely high increase and very moderate dispersion

These classes are identified in the UiTi matrix as a function of aerodynamic and thermal conditions, as shown in table 4, where the columns U1 to U5 are related to the atmosphere's aerodynamic characteristics and rows T1 to T5 to its thermal characteristics.

Table 4 - UiTi grid for the qualitative meteorological analysis of an acoustic situation.

<table>
<tr><th></th><th>U1</th><th>U2</th><th>U3</th><th>U4</th><th>U5</th></tr>
<tr><th>T1</th><td></td><td>M0</td><td colspan="2">M1</td><td></td></tr>
<tr><th>T2</th><td>M0</td><td colspan="2">M1</td><td>M2</td><td>M3</td></tr>
<tr><th>T3</th><td colspan="2">M1</td><td>M2</td><td colspan="2">M3</td></tr>
<tr><th>T4</th><td>M1</td><td>M2</td><td colspan="2">M3</td><td>M4</td></tr>
<tr><th>T5</th><td></td><td colspan="2">M3</td><td>M4</td><td></td></tr>
</table>

The input criteria for the UiTi grid are indicated in table 5 .They correspond to average values of meteorological conditions observed over a ‘short-term’ period. The aerodynamic (Ui, i=1 to 5) and thermal (Ti, i=1 to 5) classes are defined in terms of observations and vertical gradients.

Table 5 - UiTi grid input criteria and associated values for the vertical wind and temperature gradients.

Class		**Regional observations/data**	**Vertical gradients**
U	U1	Strong head wind	$Grad_{VV} < -0.13s^{-1}$
	U2	[Light head wind] OR [Only very light head wind]	$-0.13s^{-1} \leq Grad_{VV} < -0.05s^{-1}$
	U3	[No wind] OR [Cross wind]	$-0.05s^{-1} \leq Grad_{VV} < 0.05s^{-1}$
	U4	[Light tail wind] OR [Only very light tail wind]	$0.05s^{-1} \leq Grad_{VV} < 0.13s^{-1}$
	U5	Strong tail wind	$Grad_{VV} \geq 0.13s^{-1}$
T	T1	Day AND strong radiation AND dry surface AND no or little wind	$Grad_T < -0.04K.m^{-1}$
	T2	Day AND [average radiation OR damp surface OR strong wind]	$-0.04K.m^{-1} \leq Grad_T < 0.02K.m^{-1}$
	T3	[Hourly duration including sunrise or sunset] OR [dull weather and light wind and non-dry surface]	$-0.02K.m^{-1} \leq Grad_T < 0.01K.m^{-1}$
	T4	Night AND [cloudy or no wind]	$0.01K.m^{-1} \leq Grad_T < 0.15K.m^{-1}$
	T5	Night AND clear sky AND little or no wind	$Grad_T \geq 0.15K.m^{-1}$

The classification of propagation conditions based on qualitative weather observations requires the collection of meteorological data, such as wind speed and direction, cloud cover and rain rate, that can be easily measured or retrieved from existing monitoring stations.

The UiTi matrix can be further simplified taking into account that currently available acoustic models are unable to manage unfavorable conditions and they are usually replaced by homogeneous conditions. This simplification tends to overestimate the actual sound levels, but it contributes to improve receivers protection**Errore. L'origine riferimento non è stata trovata.**.

In the simplified UiTi matrix (table 6) only three states are achievable: homogeneous conditions [H], favorable or homogeneous conditions in specific wind sectors [F or H] and favorable conditions in all directions [F]).

Table 6 - Simplified matrix UiTi, where H states for homogeneous conditions, F or H for favorable or homogeneous conditions in specific wind sectors and F for favorable conditions in all directions.

Time of day	**No wind**	**Light wind (ws≤3 m/s)**	**Strong wind (ws> 3m/s)**
Day time	H	H	F or H
Sunrise or Sunset	H	F or H	F or H
Night AND cloudy	F	F or H	F or H
Night AND clear sky	F	F	-

It follows that the classification of propagation conditions can be achieved from information on wind speed and direction, and cloud cover. In the Dynamap System, these data are retrieved from existing weather stations publishing free data on the web with a time frequency of 30 minutes.

4.3 Checking sound propagation conditions with measured data

The selection of the appropriate basic noise map mainly depends on meteorological information. To check the veracity of the data retrieved from the web, four weather stations have been installed along the motorway in positions corresponding to as many wind sectors (North, East, South and West). Each weather station hosts three temperature sensors positioned at different heights (typically at z1 = 1 m, z2 = 3 m and z3 = 10 m) and an anemometer to measure thermal conditions (temperature gradient) and wind features. With this approach, the measurement of cloud cover is not necessary. Meteorological data are then converted into sound propagation conditions using the UiTi simplified matrix shown in table 8.

Table 8 - Simplified UiTi matrix, where H states for homogeneous, F or H for favorable or homogeneous conditions in specific wind sectors and F for favorable conditions in all directions.

T	**Thermal conditions**	**No wind**	**Light wind (ws≤3 m/s)**	**Strong wind (ws> 3m/s)**
T1	$Grad_T < -0.04 K.m^{-1}$	H	H	-
T2	$-0.04 K.m \leq Grad_T < -0.02 K.m$	H	H	F or H
T3	$-0.02 K.m^{-1} \leq Grad_T < 0.01 K.m^{-1}$	H	F or H	F or H
T4	$0.01 K.m^{-1} \leq Grad_T < 0.15 K.m^{-1}$	F	F	F or H
T5	$Grad_T \geq 0.15 K.m^{-1}$	F	F	-

5 PRELIMINARY RESULTS

A very preliminary test of the system has been performed by comparing the results provided by Dynamap procedure and in-field measurements in two test-sites whose coordinates in Decimal Degree (DD) and distance from GRA are reported in table 9. Both measurements are 30 mins long and performed with a class I phono-meter. Based on the weather conditions, the base map used corresponds to the WD-EAST. The results showed that the mean deviation for the two test-sites is 1.2±0.9 and 3.1±2.1 dB (table 9).

Table 9 – Preliminary results obtained in two test-sites.

Site Coordinates (DD)	Distance from GRA (m)	Base Map	Leq30m (dB)	Mean deviation (dB)
41.9549748 -12.384306	35.0	WD-EAST	56.1	1.2±0.9
41.9543834 - 12.3856563	155.0	WD-EAST	48.7	3.1±2.1

6 CONCLUSIONS

In this paper, we present the progresses achieved in the development of Dynamap project in the pilot area of Rome. Dynamap sensors have been installed and calibrated. Before being used, noise data are subject to a filtering procedure in order to remove non-traffic sources. This requested different training tests to optimize the ANED detection algorithm. A scheme of the noise mapping process has been described. Dynamic noise maps are achieved by scaling pre-calculated noise maps accounting for different traffic and weather conditions and updated according to the noise levels detected by the monitoring and meteorological stations. There are six basic noise maps prepared to take into account sound propagation conditions. The selection of the appropriate map is accomplished by converting meteorological conditions into the corresponding sound propagation conditions. Very preliminary tests on the system seem promising though further tests and fault analysis are needed to optimize Dynamap performance.

7 ACKNOWLEDGEMENTS

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