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Acoustic Conditions Analysis of a Multi-Sensor Network for the Adaptation of the Anomalous Noise Event Detector†

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Abstract: The DYNAMAP project is aimed at implementing a dynamic noise mapping system able to determine the acoustic impact of road infrastructures in real-time, due to the basis settled by the European Noise Directive 2002/49/EC. A Wireless Acoustic Sensor Network (WASN) is used to collect the measurements in two pilot areas: in the city of Milan (urban) and in the A90 motorway around Rome (suburban). For a proper evaluation of the noise level of the road infrastructures, the anomalous noise events (ANE) unrelated to traffic noise (e.g. sirens, horns, speech, doors. . .) should be removed before updating the noise maps. For this purpose, an anomalous noise events detector (ANED) has been initially designed and trained using data from a real-life recording campaign. In this work, we keep working in the adaptation of the ANED algorithm to conform to the requirements of the final 25-nodes hybrid WASN deployed in the suburban environment. Specifically, the study focuses on the analysis of the spectro-temporal characteristics of the acoustic data in real-operation conditions and their differences between the 19 high-capacity nodes in the Rome pilot area in order to adapt the ANED to run on the entire WASN appropriately.

Keywords: road traffic noise; anomalous noise event; monitoring; smartcity; WASN

1. Introduction

The number of people living in urban and suburban areas is increasing year after year [1]. As a consequence, the quality of life of citizens is being negatively affected by the increase of Road Traffic Noise (RTN) levels [2], which has been identified as one of the main sources of health-related problems [3,4]. At the European level, the prevention and reduction of environmental noise has being addressed by competent authorities based on the European Noise Directive 2002/49/EC (END) [5], and the consequent strategic noise mapping assessment CNOSSOS-EU [6], which has to be implemented by all the European member states by the end of 2018. The different pillars of these regulations are: *i)* determining noise exposure, *ii)* informing the affected citizens and *iii)* preventing and reducing the environmental noise where necessary.

Moreover, the END requires the member states to tailor and publish noise maps together with the corresponding action plans every five years for large agglomerations (with +100.000 inhabitants) and other major infrastructures. This requirement has been (and it is still being) mainly addressed by experts that collect representative acoustic data using certified sound level devices, which is subsequently fed into the corresponding noise tailoring software [7]. Nevertheless, the emergence of Wireless Acoustic Sensor Networks (WASNs) poses the possibility of monitoring environmental noise pervasively in urban and suburban environments (e.g. [8,9]).

Among these WASN-projects, the LIFE+ DYNAMAP [10] is aimed to develop a dynamic noise mapping system able to detect and represent the acoustic impact of road infrastructures in real time. Two hybrid low-cost WASNs (including high-capacity and low-capacity nodes) have been recently deployed in the two pilot areas of the project [11,12]: the first one, within the District 9 of the city of Milan, and the second one along the A90 motorway surrounding Rome, which corresponds to an urban and a suburban environment, respectively. For a proper evaluation of the noise level of the road infrastructure, those anomalous noise events (ANE) unrelated to regular traffic noise (e.g. sirens, horns, speech, doors, music, etc.) should be automatically removed from the equivalent noise level computation to tailor reliable RTN maps. To that effect, an Anomalous Noise Event Detector (ANED) has been designed and implemented to run on the 19-node high-capacity low-cost acoustic sensors of the WASN [13,14].

After a seminal design of the ANED based on a synthetic audio database [15], the core algorithm was improved and trained with audio data from a recording campaign conducted across different representative locations of the pilot areas [13]. Specifically, the Rome's suburban acoustic environment was sampled through a subset of the 19 high capacity sites of the A90 Rome motorway during short periods of time (e.g, 20-30 minutes) throughout the daytime [16]. Although the collected audio come from a real-life environment, on the one hand, it was unfeasible to consider all the factors of the WASN in real operation; i.e., working 24 hours/day, and during days of different traffic activity (e.g. weekdays and weekends). On the other hand, the measurements were performed using a tripod placed over the highway portal floors with an oblique orientation during the recording campaign [16], which differs from the final position of the low-cost sensors in the WASN.

In [17], the first steps to adapt the ANED to run in the final operation conditions of the WASN were presented, after deploying the low-cost high-capacity nodes in the Rome pilot. That work covered two main stages: the first one was focused on the validation of the performance of the preliminary ANED version on the real-life operation data, and the second one focused on the process followed to collect new data from the sensors of the deployed 19-nodes WASN. After the manual labelling of a representative subset of the recorded data, a significantly larger and richer dataset was obtained than the one obtained from the recording campaign (e.g., new ANE categories were included), being the new one composed of around 107 h of audio. After the results in [17], where the ANED did not perform suitable results in terms of accuracy, in this paper we present the next step consisting in a subsequent analyses carried out on the 107 h of real-operation audio data recorded. The final goal of this study is to analyze the spectro-temporal patterns of the noise received by each sensor in order to determine to what extent is necessary to adapt the ANED to run on all the nodes of the WASN appropriately.

The rest of this paper is structured as follows. In Section 2, a detailed description of the operating conditions of the Rome pilot area is given. After that, in Section 3, a spectro-temporal analysis is conducted on the audio data obtained for each high-capacity node of the network. Finally, Section 4 presents the conclusions derived from this research.

2. Description of the Real-Operating Conditions of Rome Pilot

The WASN of the suburban area of the ring Rome is comprised of 24 acoustic sensors, 5 of which are low-capacity sensors without enough computational resources to allocate the ANED. The locations where the 19 high-capacity sensors of the WASN in the Rome's suburban pilot area are shown in Figure 1; in red those that were also sensed during the initial recording campaign. These are the locations where the real-operation recordings are conducted to provide the acoustic data to re-train and validate the ANED performance in the final locations of the sensors.

The system requires a robust and stable behaviour as it operates 24 hours a day 7 days a week. Thus, the ANED training must include as far as possible all kind of situations of the real life. This is a very challenging task, which is difficult to accomplish if the amount of available resources is limited, e.g., processing and storage capabilities. However, in the aim of giving a solution to this goal,

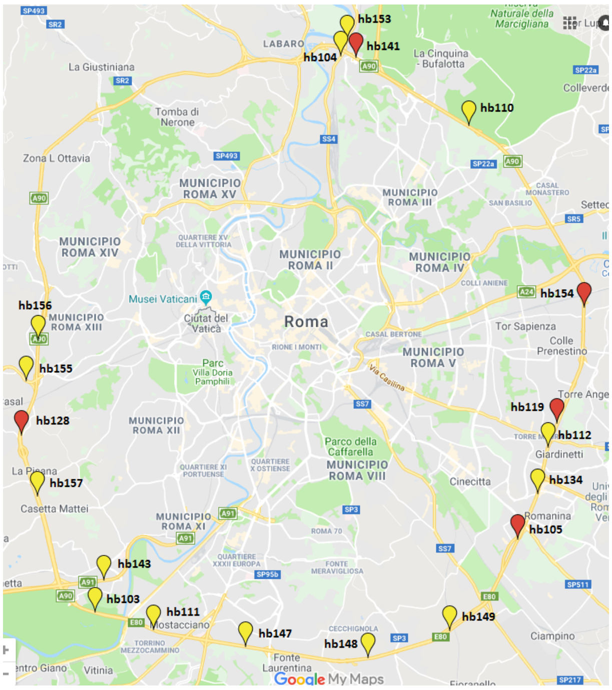

Figure 1. Map with sensors location information within the WASN of DYNAMAP project.

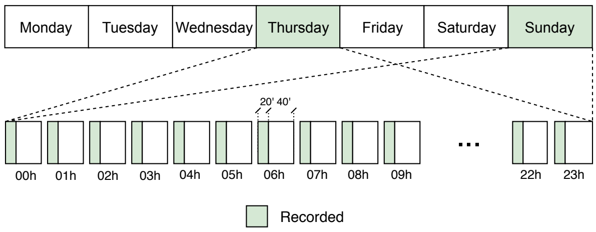

Figure 2. Diagram of the recording days and duration for each sensor.

our approach has been to plan one-day real-operation recordings of all WASN's sensors, considering different days of different traffic conditions: Thursday as a weekday and Sunday as a weekend day, i.e, 2^{th} and 5^{th} Nov 2017 respectively. From each sensor, 20 minutes have been recorded every hour. In Figure 2, an schematic diagram showing the recording weekdays is shown and also the recording duration is depicted. As a result, 16 hours have been taken into consideration for each location, having a diversity belonging to a workday and a holiday and a representation for each hour of the day. After the performed labelling, these data may be used to properly re-train the ANED and improve its accuracy.

3. Acoustic Spectral Analysis of the Nodes of the WASN

In this section we analyze the spectral distributions for each sensor and also for each hour using the available audio recordings. The analysis has been performed using the Gammatone filterbank as a spectral representation due to its high coherence with mammals sensitivity, and it has been implemented following the approach of the Gammatone Cepstral Coefficients (GTCC) which was proposed in [18]. Acoustic signal frames of 30 ms have been windowed using a Hamming window [19], and 48 subband energies have been obtained between 20 Hz and 22 kHz. Using the 20 minutes audio file of a given sensor, a mean spectrum has been computed, and the 24 mean spectra have been compiled to define the spectrum-time profile of this sensor during the analyzed day.

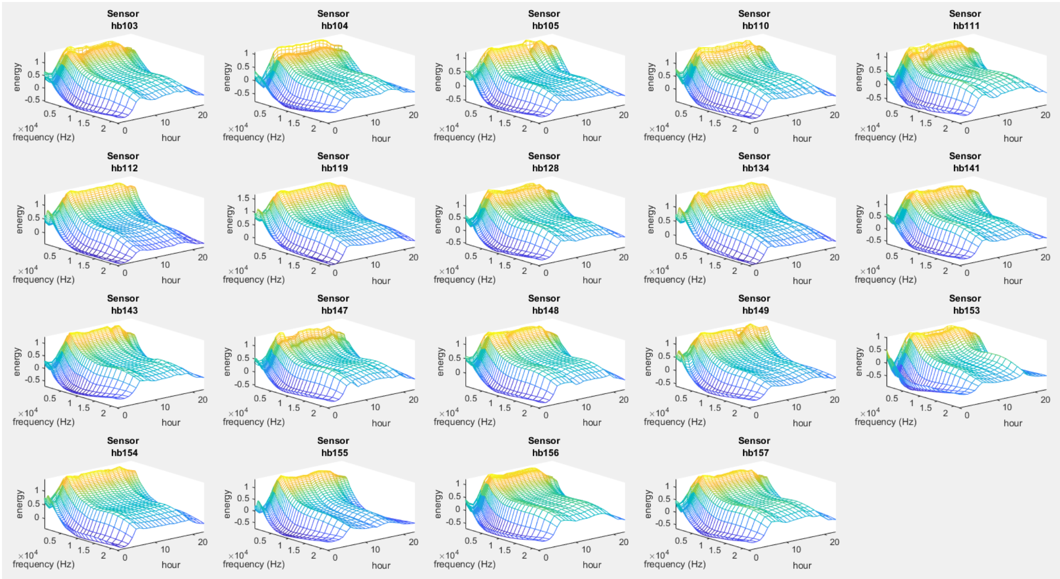

Figure 3. Spectrum-time profiles of the 19 sensors of the WASN during weekday (2^{nd} Nov. 2017).

The spectrum-time profiles of the 19 sensors of the WASN for the weekday are shown in Figure 3. All sensors profiles follow a gross similar pattern, which can be basically attributed to road traffic noise (the major class): higher noise levels are obtained in the lower frequency band, and also higher amplitudes are observed in the time region of higher traffic density (between 6:00 and 21:00). Nevertheless, it can be also appreciated some more fine variations between sensors profiles, which informs about dissimilar behaviour of the type of traffic conditions and noise events in these specific locations.

In Figure 4 the spectrum-time profiles are shown for a weekend day, where sensor hb119 was active only between 00:00 and 13:00 (the rest of values in its profile have been fixed to 0). In this case, high energy values can be observed at 14:00, coinciding with rain sound. Besides, comparing this figure with the previous Figure 3, several similarities can be observed among these. Sensor hb112 and hb134 show low energy values at high frequencies in both Figures, and the reader may observe that both are located very near in Figure 1. However, sensor hb119 is also located near the mentioned two but its high frequencies present higher energy values in both dates. On the other hand, sensors hb103, hb111, hb143, hb156 and hb157 show high energies at high frequencies in both days and are all located in the south-west part of the Rome ring-road. In the northern part of the ring-road, sensors hb104, hb141 and hb153, however, its energy profiles are only similar between hb104 and hb141. When the eastern part is concerned, hb112 and hb119 are also located nearby, and both present a similar spectrum-time pattern having hb119 sensor a higher energy overall. As seen, most sensors located nearby present a similar energy profile or pattern, however, a more detailed analysis should be conducted to better characterize and quantify the differences between the spectrum-time profiles. In figure 5 the spectrum-time profiles of only one sensor (hb103) are shown for the two analyzed days in order to better explore the inter-week differences. As can be observed, the mean monitored road-traffic noise in a certain location present significant differences when one weekday is compared with a weekend day, e.g. the raise time of traffic noise at morning and its drop in time at the evening show a more soft behavior during weekend.

In order to better take advantage of all available data, more analyses should be conducted to conclude to what extent the differences of the observed spectral-time profiles can be relevant to propose, e.g., performing clustering of sensors to train the ANED differently in each group.

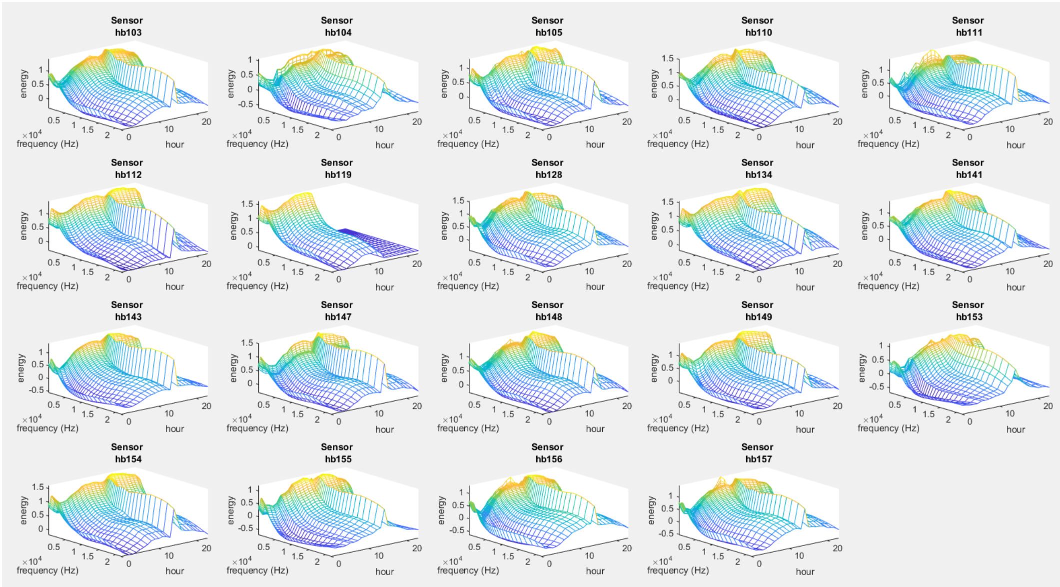

Figure 4. Spectrum-time profiles of the 19 sensors of the WASN during weekend (5^{th} Nov. 2017).

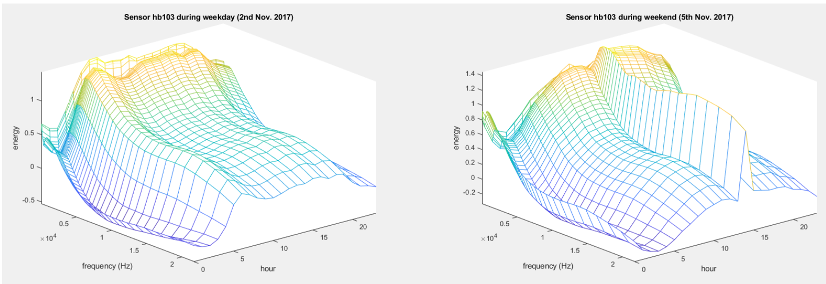

Figure 5. Spectrum-time profiles of the sensor hb103 (2^{nd} and 5^{th} Nov. 2017).

4. Conclusions

The several recording locations have a different acoustic profile, having an effect on the sound levels as well as the ANED performance. For this reason, it is of great importance to study the acoustic conditions of the sensors composing the sensor network. In this paper, the acoustic profiles of the high-capacity nodes from Rome WASN are described in detail, in order to find out the differences among them, if present. Also, the difference between two different days are analyzed, considering a weekday and a weekend day, 20 minutes for every hour of the day. In the last phase of the DYNAMAP project, the authors are conducting the fine tuning of the acoustic sensors to adapt each node of the network and improve the individual performance. This study is focused on analyzing the acoustic profile of the nodes in an attempt to figure out the sensor network uniformity and to use this information in the next training of the anomalous noise event detector. Future lines include measuring the acoustic differences of each sensor and comparing these metrics with the event detection accuracy.

Author Contributions: J.C.S. conducted the experiments of spectral analysis and wrote a part of the paper. R.M.A.P. also helped to design the experiments and wrote another part of the paper. F.A. and F.O. analyzed the results of the spectral distribution computations and wrote parts of the paper.

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Conflicts of Interest: The authors declare no conflict of interest.

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