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LIFE – DYNAMAP
Dynamic Acoustic Mapping – Development of low cost sensors networks for real time noise mapping

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Author(s):	Rosa Ma Alsina Pagès, Joan Claudi Socoró, Francesc Alías, Andrea Cerniglia, Luca Nencini
Reviewer(s):	Patrizia Bellucci
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Contact person:	Patrizia Bellucci
Postal address:	ANAS S.p.A – Centro Sperimentale Stradale Via della Stazione di Cesano, 311 00123 Cesano di Roma (RM) ITALY
Telephone:	+39 06 44463713
Fax:	+39 06 3038585
E-mail:	p.bellucci@stradeanas.it
Project Website:	www.life-dynamap.eu

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1. INTRODUCTION

This action aims at investigating different ways of exploiting the implemented system for traffic noise dynamic mapping in the future. Having a real-time map of traffic noise allows the development of multiple mitigating, corrective, informative and enriched action plans.

The mitigating applications of the system are related to long-term measures. Based on the data acquired by the system, the most critical areas in terms of noise pollution can be identified. Thus, action plans developed to mitigate the noise impact on people who live and work in those areas could be more effectively addressed and evaluated. For instance, actions such as the construction of acoustic barriers, traffic-calming policies or the installation of low-noise asphalt could be efficiently designed thanks to the data provided by the dynamic mapping system.

The detection of high traffic noise levels in certain areas at specific moments can be used for short-term corrective purposes, for example, for the development of an early warning system based on the interconnection between the dynamic traffic noise mapping system and electronic roadside informative boards. This system could be used to inform drivers of alternative routes. Another application could be displaying informative messages oriented to reduce current noise levels, such as dynamic speed limits adapted to traffic status, “moderate your driving style” messages, or also to temporarily limit the circulation of certain types of vehicles.

The data gathered by the system can also be exploited for informative purposes. This type of application ranges from the inclusion of real-time traffic noise levels in environmental information boards (alongside with meteorological, air pollution or pollen count data, among others) to the more commercial use of these data in sectors such as housing or tourism.

Finally, enriched applications based on a deeper analysis of the noise data captured by the system could also be developed. Making use of the spectral decomposition of the noise signal provided by the high computation capacity sensors, it could be possible to go further than traffic vs. non-traffic noise discrimination. The idea is to recognize several types of noise sources, which will allow the generation of dynamic maps of different noise sources such as rail, cars, trucks, or aircrafts, for instance.

2. ROAD TRAFFIC MANAGEMENT

2.1. STATE OF THE ART

The deployment of Wireless Acoustic Sensor Networks (WASNs) in several European countries has opened up some challenges, especially those derived from network and hardware platform design, together with data collection plus their subsequent audio signal processing (see [Bertrand2011] and [Griffin2015] for further details). For instance, it is worth mentioning that none of the approaches described in [Basten2014] take into account the identification of traffic typology (e.g., light or heavy traffic).

In [Sobreira2008], three type of traffic sources (trucks, cars, and motorbikes) were classified using k-Nearest Neighbour (KNN), Fischer Linear Discriminant (FLD) and Principal Components (PCA). A set of 5 type of audio features were analysed in the study, which included zero crossing ratios (ZCRs), spectral centroids, spectral roll off, subband energies and Mel Frequency Cepstral Coefficients (MFCC). The audio database was obtained in a flat road with middle density traffic, but without including audio passages with multiple traffic noise at once nor recordings with high background or wind noise. The experiments obtained in those conditions a classification error as low as 17.19%.

In [Ntalampiras2014], a system for acoustic surveillance in urban traffic environments following a multi-class Acoustic Event Detector (AED) was introduced. This approach was based on a two-stage Hidden Markov Model (HMM) classification system with a short-term analysis windowing of length 30 ms, and analysed a multidomain feature set, including MFCC, MPEG-7 low-level descriptors (LLD) and Perceptual Wavelet Packets (PWP) to consider the time, frequency and wavelet domains. This work included a database (from several professional sound effect collections) composed of nine audio classes: car, motorcycle, aircraft, crowd, thunder, wind, train, horn and crash. Although the two first classes belong to road-traffic noise (RTN), the experimental configuration of the proposal is far from that obtained in real-life recording conditions since the events of interest are artificially mixed with background noise.

In [Sharma2016], two adaptive neuro-fuzzy models were developed for traffic classification and noise prediction. The developed system classifies the vehicles into three categories, i.e., light vehicle (scooter and motorcycle), medium vehicle (cars, auto and jeeps) and heavy vehicles (trucks and buses), considering as audio features. ZCR and mean spectral centroid. However, the system was validated using a very short audio database (including only 100 samples for each category), which limits the generalization of the obtained results.

In [Maijala2018] the authors design a classifier which goal is also to separate between target and interfering noise. The activity of the noise source is detected by means of a binary classifier discriminating between the target, which can be plant or aircraft noise, and the background, which can be traffic, wind, rain, thunder, etc. The algorithm is based on MFCC [Mermelstein197] 100 ms window length feature extraction with the classification using a supervised classifier (GMM and Artificial Neural Networks or ANNs), trained with an annotated real-life dataset

2.2.PROPOSAL

In the aim of enriching the dynamic road-traffic maps, the developed Anomalous Noise Events Detector (ANED) in the framework of the LIFE DYNAMAP project [Socoro2017] could be further developed to discern between different types of road-traffic noise sources. The distinction could be focused on those placements where there is more interest on obtaining this type of low-level information, e.g. to activate restrictions to heavy and long trucks or to vehicles with very annoying engines, being also useful to detect possible environmental infractions.

The redesign of the algorithm would need to perform new studies with traffic noise samples gathered through the DYNAMAP's WASN, which will entail an in-depth labelling of the collected data using new RTN categories, as well as the subsequent validation of the ANED algorithm performance in order to evaluate the degree of reliability obtained when different types of vehicles are considered. This update will also cause significant modifications of the software running in the sensors as well as the one that builds the noise maps in real time, to cope with this detailed information to derive enriched or new types of noise maps views or layers.

We envision that this future line will require higher computational capacity associated with the detection of noises distributed (i.e. running in the sensor) despite maybe the current high-capacity sensors of the WASN could suffice. In addition, the geographic information system (GIS) platform to show the maps could be affected, because one of the goals of detecting different types of RTN is for informative purposes, and this distinction should be present in the maps built in the GIS platform.

3. IDENTIFICATION OF NOISE CONTRIBUTIONS

In complex acoustic environments, many noise sources contributing to high equivalent noise levels can be found. Depending on the location of the measure, RTN may be the dominant source, but in other situations, this could come from leisure, industry or even ports. The European Noise Directive (END) [EU2002] regulation requires the distinction of noise source to carry out a study of their impact on people. To that effect, the first step to address the problem is determining which types of noise sources should be considered in each scenario. In airport or port environments, the types of sound that may appear beyond road traffic noise should be specified, and the same in the case of areas markedly dedicated to leisure.

Regarding responsibilities for the noise sources, the END provides a basis to develop measures to reduce noise depending on its source at the European level [Juraga2015].

Among the measures adopted by the European Union (EU) to address noise depending on its source (e.g. vehicles, airports, railway tracks), it can be cited the introduction of noise-related operating restrictions at European airports within a balanced approach (EU/598/2014) and the regulation on the sound level of motor vehicles and of replacement silencing systems (EU/540/2014), both adopted on April 16th, 2014. Once the contributions corresponding to each noise agent have been determined, it is necessary to be able to automate the detection of certain acoustic events that support the generation of more reliable noise maps.

In order to provide reliable road-traffic noise maps, those events non-related to regular RTN should be removed from the monitoring of the impact of road infrastructures [Orga2018]. To this aim, the vision of the LIFE DYNAMAP project aims to detect and delete abnormal noise events to provide the final user with a RTN map. In order to ensure that subsequent studies only consider the impact of road traffic noise on the well-being of citizens, those noise sources unrelated to RTN should be removed from the study as they could alter the conclusions significantly. This is usually assured by experts conducting the acoustic measurements, but recently this function has been automatized by means of the aforementioned ANED algorithm as shown in the report related to Action B3 [Socoro2017,<2018].

Several projects pretend to detect specific noise events, as shotguns, horns, road accidents, etc. In [Paulo2015] and, more specifically, road-traffic accidents are identified by detecting tire screeching and crashes [Foggia2016]. Moreover, distinguishing among different types of anomalous noise events could be also of interest to provide relevant information to the competent authorities, besides the distinction of different types of traffic. For instance, it could be interesting to determine whether the sensor is located within an area with abundant ambulance noise - perhaps near a hospital - or an area with regular children's play such as a children's school or a park, or even a nightlife area. These other types of acoustic environments also impact on the population, and since the LIFE DYNAMAP project has developed a system to detect when a noise source does not come from RTN, the capability of distinguishing a predefined set of noise sources, could enrich the system. More details about the main characteristics of anomalous noise events of urban and suburban soundscapes can be found in [Alias2017].

For the execution of this future line, we envision that the sensor should be endowed with more computational capacity in order to allow the operation of more powerful machine learning algorithms than the current ones implemented to distinguish between more noise classes. Moreover, the GIS platform should be properly adapted to show the occurrence data of other types of noise sources other than RTN.

4. SUBJECTIVE AND PERCEPTUAL SENSING WITH CITIZEN PARTICIPATION

One of the areas of most interest today is citizen participation in science, particularly concerning the environment. The concept of 'participative sensing' has become especially strongly following a hybrid approach, where the objective is to measure in a regulated way data and complement them with the participation of citizens providing concrete data, perceptions or specific measures in particular places.

4.1. STATE OF THE ART

The idea of the participative sensing can be linked to the definition of the “citizens as sensors” paradigm [Mostashari2011]. In this case, tools and protocols should be predefined to allow information integration of all of the individual measurements (e.g., when uploading geolocalised photos in Google Maps, reporting traffic accidents in the Waze application, etc.).

In [Santini2009], the authors reviewed the approaches already presented by the wireless sensing research community to assess noise pollution using both acoustic sensor nodes and mobile phones. Since then, several works have been published dealing with the integration of the results of individual measurements. This approach increases the number of potential measurements to be evaluated in the integration of the data, which is usually non-equally distributed in the city and not stable in time either, thus, it makes the final noise mapping integration a complex problem. Moreover, the fact that the devices used for the measurements are not technically checked and calibrated can lead the entire system to present a non-stable performance in terms of accuracy, so, the citizen measurements should not be considered with the same reliability as the sensor-based measurements. The NoiseSPY project [Kanjo2010] designed a sound sensing system considering a mobile phone as a low-cost data logger to monitor environmental noise; citizens were allowed to visualize in real time noise levels in different places of the city. The NoiseTube project [Maisonneuve2010] provides a low-cost solution for the citizens to measure their personal exposure to noise in their everyday life by means of a mobile application that evaluates noise using the smartphone. Furthermore, the system allows citizens to participate in the generation of a collective noise map using the geo-localized measurements. In [Schweizer2011], an application named NoiseMap is presented, which gathers loudness data and transfers them to an open urban sensing central platform. Afterwards, the data become public by means of a web-based service. In [Hu2015], the participative sensing contributes to updating a previous noise map of the city in order to dynamically refine the granularity of the noise patterns on different places. The frequency of updating depends on the level of participation of citizens in each road segment.

The Sounds Of The City project [Ruge2013] is focused on the measurement of the noise level that surrounds a citizen. The citizen can measure the loudness of his/her environment using a simple smartphone application, which sends the data to a central server where all the data are aggregated before computing and plotting the visual noise map. This idea was also exploited in a platform that modelled the noise situation of New York City considering three dimensions [Zheng2014]: the region, the type of noise and a time stamp. From the collected data, a noise pollution indicator is inferred from the intelligent composition of noises measured by citizens.

One of the most recent trends in analysing the acoustic data obtained from citizens is distinguishing between pleasant and unpleasant sounds, analysing the relationship between soundscapes and emotions, as well as the relationship between soundscapes and people's perceptions [Aiello2016]. In [Li2018] the authors describe the calibration method for sound pressure levels (SPL) measured by mobile phone, analyse the Participative Soundscape Sensing (PSS's) data temporal-spatial distribution characteristics, and discuss the impact of the participants' age and gender on the data quality. Furthermore, they analyse the sound comfort level relationships with each class of land use, sound sources, subjective evaluation, sound level, sound harmoniousness, gender, and age using over a year of shared data.

Nowadays, this approach is gaining in importance since almost any smartphone can be used as a tool to sense citizens' environment. On the one hand, authorities are interested in having real-time data measured in the city, especially in critical noisy places, and on the other hand, citizens are interested in reporting noise excesses in their surroundings.

4.2. PROPOSAL

Nowadays, the participative science is one of the trendiest topics in the framework of the smart cities. The everyday technology allows the citizens to conduct simple measurements, and in the case of noise, this is not an exception. It would be a good advance in the objectives of the LIFE DYNAMAP project if a mobile application were developed so that citizens could add reliable data – not only acoustic measurements, but also environmental information – collected in different places, both in Milan (urban) and Rome (suburban). At the same time, the proposal could include a description by users of the perception of annoyance produced by noise at different points in the urban or suburban area, hence, allowing the inclusion of a type of information that can only be obtained through citizens' participation. In the future, studies on the correlation between annoyance and noise levels, as well as types of noise, could lead to new measures for the reduction of noise pollution at certain points of the road network [Labairu2018].

Bearing in mind that the number of sensors in the network is limited, citizens contributions can be considered complementary information, even though less reliable. These new data coming from citizens' participations could enrich significantly the DYNAMAP noise mapping system within the city enabling detection of alerts in terms of critical or relevant noise disturbances that deserves priority actions from the competent authorities.

5. AIR QUALITY MONITORING

5.1. STATE OF THE ART

Environmental monitoring services such as ekoNET [Pokric2014] can measure both meteorological and pollutant variables like atmospheric pressure, temperature, humidity, and concentrations of gases in the air (e.g., CO2, CO, O3, NO and NO2). However, these stations do not include traffic noise as a possible income of useful information in the aim of increasing the accuracy of these measurements, taking into account the low stability of the electrochemical gas sensors, ageing, cross-sensitivity and impact of the air temperature and humidity on the readings.

In [Can2011], a correlation analysis was carried out in order to investigate the relation between ultrafine particles (UFP, diameter<100 nm) counts with data coming from low-cost sensors, most notably noise sensors. Traffic intensity or noise level data were found to correlate with UFP to a lesser degree than combination of nitrogen oxide and dioxide (NO and NO2) did. Although correlations remain moderate, sound levels were found to be more correlated to UFP in the 20-30 nm range. Prediction with noise indicators is even comparable to the more-expensive-to-measure NO(x) for the smallest UFP, showing the potential of using microphones to estimate UFP counts.

In [Pariseau2018], a crowdsourced air quality monitoring system is detailed. Such a system could provide information beyond the user's local instrument on air quality over a much larger area. This information could be used by a user to make decisions about frequenting particular areas based on the results, or to alert them to changing conditions in the area so that the user might act before local conditions change.

In [Singla2018], the authors review the studies (especially in the last decade) done by various researchers using different kinds of environmental sensors highlighting related techniques and issues. They also present important studies of measuring impact and emission of air pollution on human beings and discuss models using which air pollution inhalation can be associated to humans by quantifying personal exposure with the use of human activity detection.

5.2. PROPOSAL

Another possible future line of the monitoring system developed within the LIFE DYNAMAP project includes the measurement of other parameters associated with quality of life, such as any environmental factor (CO_2, CO, O_3, NO and NO_2), to characterize environmental pollution. If the noise comes from traffic, it is likely that both equivalent noise level and air pollution will increase at the same time, although it is known that CO_2 levels in the city also depend on the climate. This last point should also be incorporated so that firm conclusions could be drawn from the total amount of data gathered from each of the sensors.

Logically, this vision of a future development of the system requires modifications of the sensor hardware (in order to be able to incorporate the CO_2 sensor, etc., and the meteorological sensor), but it also makes the evaluation of signals in GIS-based noise mapping system more complex, since it will be necessary to look for cross-dependencies between all the data collected. The throughput of data from the sensor to the cloud must also be higher than the one currently required by the system.

6. NOISE AND HEALTH

Environmental noise pollution is increasing year after year, because of population growth and the consequent expansion of transportation systems, including highways, railways and airways [EU2017]. It is the origin of not only annoyance, but also of severe effects on the health of the citizens [Muzet2007, Hygge2002, Dratva2012].

Research also specifically analyses the association between RTN and several diseases in suburban and urban areas. The influence of road-traffic noise implies an increase in tiredness and disturbs the sleep [Ohrstrom2006], besides annoyance stated in [Botteldooren2011] for neighbourhood. Finally, it is worth mentioning that the most significant noise source in urban areas is road traffic noise, according to the interviewed residents in Belgrade [Jakovljevic2009].

For this reason, our vision in the LIFE DYNAMAP project is to automate the task of noise monitoring in agglomerations and major roads using a WASN that provides real-time operation. This allows administration to have available short-term information to study about the impact of the noise variations to inhabitants. In addition, noise event detection is implemented in order to classify the recorded audio in road traffic noise and anomalous noise events. This way, the noise levels of road traffic can be analysed independently of other abnormal events that happen in the streets or roads that could belong to human activity or natural phenomena. The goal is to provide reliable road-traffic noise maps after removing the event non-related to road traffic that could be used in other health studies.

The DYNAMAP system could be upgraded to provide at first raw data on the impact of noise on people for scientists working in epidemiology. The knowledge of the equivalent level of the traffic noise in the locations where a sensor is deployed, together with the possibility of knowing the impact of other types of noise sources (e.g., ambulances, horns, leisure noise, etc.) could bring us closer to a much more detailed knowledge of how this level of noise affects people's quality of life. From this starting point, epidemiologists could have much more detailed information about population noise exposure. To this aim, the DYNAMAP acoustic measurements could be used to support epidemiologists' investigations, who should carry out their clinical studies on receivers located in the areas covered by the corresponding study.

This future line affects both the sensor, which would need more computing capacity, and the storage capacity of the cloud to consider all the parameters that epidemiologists need to record and display.

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