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B8 - Future system upgrade and analysis of the potential integration of further environmental parameters

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

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1. THE DYNAMAP SYSTEM

The LIFE-DYNAMAP project (Dynamic Acoustic Mapping - Development of sensor networks at low cost for real-time noise mapping) aims to develop an automatic dynamic noise mapping system capable of detecting and representing in real time the noise impact due to road infrastructure. The aim of the project is the European Directive 2002/49 / EC on the assessment and management of environmental noise (END), which refers to the need to update the noise maps every five years, as indicated in the END.
The development of the system is practically finished and the web portal of Rome and Milan are active and available on the main page at address http://www.life-dynamap.eu.
This report refers to action B8 (future update of the system and analysis of the potential integration of further environmental parameters) and more in detail to activity B8.1 - Hardware upgrade, activities B8.2 - ANED update and activities B8.3. - Software update. In this action, a detailed investigation was developed on the problems encountered and on the possible future update in order to identify how to improve the system and extend its capabilities to make it useful for masking and representing other environmental parameters.

1.1. GENERAL DESCRIPTION OF THE SYSTEM STRUCTURE AND CAPABILITIES

The Dynamap system is composed of low-cost sensors that measure the sound pressure levels emitted by the noise sources present in the area to be mapped and by a software tool based on a GIS platform that updates the acoustic maps in real time. The sensors have been specifically developed for the Dynamap system in order to satisfy some requirements such as low cost, implementation of anomalous noise detection algorithm (also purposely developed), low power consumption and total remote control of the measuring device. As for the software part of the system, the platform chosen was based on open source operating system in order to avoid the cost of the license and to have total control of the system itself.

1.2. DESCRIPTION OF THE PROBLEMS ENCOUNTERED IN THE CURRENT CONFIGURATION

1.2.1. HARDWARE

The main problems encountered in hardware design were related to two factors: MEMS microphones selection, in terms of performance related to the specific application, and general component selection in terms of their long-term availability.

As for the microphone, the choice of the right component required a deep investigation in order to find stable microphones with the needed characteristics, usable in the specific environment. In fact the market offers a very wide range of MEMS sensors and new product are continuously developed, but in general they are not intended for measuring purposes, moreover in external and severe environment as it can be in Dynamap application, where the microphones are placed permanently very close to roads and exposed to humidity and aggressive environment. So, for this reason, the selection of the right component required many tests, including salt spray fog corrosion testing to check the behavior of the microphones in terms of possible faults due to the environment and/or possible changes in its characteristics over time. It is interesting to point out that some MEMS microphones showed a decrease of sensitivity as function of time, but this aging phenomenon occurs only if the microphone is powered.

As regards the long-term components availability, this is not a secondary aspect. In fact, due to the continuous development of new components, their life has become increasingly shorter. In an innovative application such as Dynamap, where development takes time also due to the different tests in different conditions, the problem of selecting a device that has become obsolete when it is selected can lead to a redesign of part of the hardware, resulting in lengthening of development timelines.

1.2.2. SOFTWARE

The main problems of the software component were related to the calibration of the ANED algorithm and to the calculation algorithm optimization.

As for ANED, given its sophistication, its tuning required a very profound analysis and tests that involved subjectively listening to portions of acquired audio signals, in order to make it more robust and adaptable to different noise scenarios according to the different situations encountered in the field.
As for the calculation algorithm optimization, the main problem was related to the needs of very fast algorithm to produce and publish maps every thirty seconds.

1.3. DESCRIPTION OF FUTURE UPGRADE OF THE SYSTEM TO SOLVE THE PROBLEMS

Regarding the choice of microphones, the gained experience has highlighted the need for in-depth tests in relation to the specific application. It is to be hoped that in the future sensors with features that are declared compatible with applications in a severe environment will be made available on the market. In any case, direct contact with the various manufacturers could simplify the whole process.
As regards the implementation of the ANED algorithm, experience has shown the need to introduce subroutines and calibration factors depending on the specific context where the sensor has to be installed. Regarding the acoustic signal sensing features of an improved version of the DYNAMAP system, the inclusion of high directivity sensing techniques would allow enriching the gathered signals with additional information from the sensed environment, i.e. spatial localization of noise sources, which in turn could allow the system to obtain higher reliability to better distinguish between road traffic noise (RTN) and anomalous noise events (ANE). To this aim, high directive microphones could be considered and explored to cope with the problem at hand. This would include exploring beamforming techniques using arrays of acoustic sensors [1]-[3] as well as ambisonic microphones [4], and the planned research would also incorporate detection of angle of arrival of noise sources and spatial filtering techniques applied to the targeted sounds. An in-depth research would be appropriate by considering all the different variables that can influence the distinction between those interfering ANE signals and RTN (e.g. direction of arrival, proximity to the sensor, type of acoustic wave fronts, number of noise sources, etc.), so as to describe which type of situations would allow the ANED to take higher benefit from the new high directivity

sensing scenario. Moreover, a study regarding the type of environment to be sensed (e.g. urban, suburban) would make sense in order to explore to what extent the use of that type of signal processing techniques can be useful or appropriate for each scenario case.
As for the calculation time, this depends upon the complexity of the system in terms of number of map to be scaled and summed, extension of the area (number of points to be calculated), number of parameter to be computed and required update time. In any case the best solution is to use a scalable virtual machine in order to have all the needed power. Today, many hosting companies offer solutions of this type at affordable costs.

2. EXTENDING THE DYNAMAP SYSTEM CAPABILITIES

At the beginning of the project, one of the objectives was to design a system capable of implementing a dynamic graphical representation of any environmental parameter, starting from noise to air quality, traffic, weather conditions, etc.
These implementation, which finds reason in the perspective of informing the population about the conditions in which it lives, would make Dynamap an integrated system of environmental representation that would contribute substantially to the realization of 'Smart Cities'.
Additional sensors and algorithms are therefore provided and in general can be easily integrated into the system thanks to its open architecture. The investigations on the possible future upgrade have been divided into four activities, as described in the following paragraphs.

2.1. MONITORING AND MAPPING AIR QUALITY

2.1.1. GENERAL DESCRIPTION OF THE SYSTEM UPGRADE

The upgrade of the air quality monitoring and mapping system is aimed at acquiring, storing and mapping air quality parameters. This update involves the use of dedicated sensors and the extension of the acquisition and representation software as well as the database where

parameters have to be stored. Thanks to this upgrade it will be possible to map air quality data in real time and to query the historical data to see the evolution of these parameters over time for statistics and future studies.

2.1.2. HARDWARE UPGRADE

The system upgrade essentially involves the integration of specific sensors for the acquisition of the parameters of interest.

For air quality there are CMOS components based on MEMs technology that can detect CO, NO2 at an affordable price (tens of euros). More expensive (hundreds of euros) is the detection of CO2 and O3. Since the monitoring station developed for noise measurement already foresees the acquisition of electrical signals coming from other sensors and their transfer to the data collection server, these features can be implemented after the realization of a protection and a fixing system with small changes to the electronics and at low cost (a few dozen euros).

Also for air particle there are sensors in the range of dozen euros that can measure PM2.5 and PM10.

2.1.3. SOFTWARE UPGRADE (INCLUDING ANED)

The software upgrade essentially involves the creation of a new specific database for the additional parameters, the creation of a specific ANED algorithm (more simple to implement since the air quality data are much less complex than the acoustic data and anomalies, due to malfunctions or local phenomena, are actually detectable by identifying sudden concentration changes limited to the single sensor) and the extension of the map representation to the specific parameters.

2.1.4. TECHNICAL AND ECONOMIC IMPACT

From the technical point of view, a first analysis does not seem to have any particular problems even if, of course, a preliminary testing phase is necessary to highlight any possible critical issues.
From a purely economic point of view, the costs for extending the system, in addition to the aforementioned sensor costs, are mainly costs for some preliminary investigation and then the extension of the software that could be quantified in twelve man months in the first analysis.

2.2. MONITORING AND MAPPING METEOROLOGICAL CONDITIONS

2.2.1. GENERAL DESCRIPTION OF THE SYSTEM UPGRADE

The upgrade of the system to report meteorological conditions involves the acquisition, storage and mapping of the related parameters. This upgrade includes the use of dedicated sensors and the extension of the acquisition and representation software. Thanks to this upgrade it will be possible to map the meteorological data in real time and to query the historical data to see the evolution over time and carry out statistics and specific studies about it.

2.2.2. HARDWARE UPGRADE

2.2.2.1. COMPLETE METEO STATIONS

If we refer to a weather station as a stand alone product, there are mainly two large families of devices: a very economical system for hobbies applications and very expensive products for professionals. For low-cost systems there is normally no possibility of interfacing them or, if an interface is present, the protocol is unknown and can only be used together with the associated software running on a PC; practically this type of device cannot be used for the

Dynamap application. Furthermore, the base station enclosure of this family of devices is not designed for external application. Professional stations can make all the necessary measurements in the best possible way, but the cost is not suitable for this specific application. There are few good products on the market at an affordable price (hundreds of euros), but in any case the price of this type of weather station is higher than the price of the entire noise monitoring station. For data transfer, this type of sensor can be supplied with rs-232 interface, which can be easily implemented in noise monitoring.

On the other hand it is important to keep in mind that the main parameters to be considered during noise measurements are the presence of rain, along with the speed and direction of the wind. For rain detection and wind speed measurement there are several commercial sensors at very affordable costs, which can be easily interfaced with the already developed noise monitoring system. Wind direction measurement is more complicated due to device costs. Measurement of wind direction is less important when noise propagation occurs over short distances as inside cities.

2.2.2.2. RAIN SENSORS

From the acoustical point of view it is not so important to measure the rain rate, but it is always necessary to know if it is raining or not, because in case of rain, the noise measurement is affected by the rain sound pressure level and the noise coming from the vehicle's wheels on the wet road. Most of the simple sensors are based on the measurement of the electrical resistivity of a special shaped printed board circuit: pratically, if the electrical resistivity is high it means that it is not raining, whereas if the electrical resistivity drops down some water is present on the sensor. Thus, for the implementation of rain detection in the system, is enough to design a very simple electronics and implement the corresponding firmware, plus some fixing and enclosure. The cost of the rain sensor is around one euro.

2.2.2.3. WIND SPEED SENSORS

In the same way, wind speed can be easily measured by using cheap three cup analog output anemometer (normally used in motorized balcony tent applications). Output signal can easily be read by the noise monitoring station and its price is around 50 euro. Even in this case it is necessary to design a very simple electronics and implement the corresponding firmware, plus some fixing and enclosure.

2.2.2.4. WIND DIRECTION SENSORS

As for wind direction, it is quite difficult to find cheap sensors for detecting wind direction. Excluding ultrasound devices, which are very expensive, the cheapest sensors are mechanical and they are mostly integrated with wind speed detectors. In any case, at the date of this document, nothing was found for a price less than hundreds of euro.

2.2.3. SOFTWARE UPGRADES (INCLUDING ANED)

Also for meteorological data the software update essentially involves the creation of a new specific database for the additional parameters, the creation of a specific ANED algorithm (again simple to implement since meteo data are much less complex than the acoustic data and anomalies, due to malfunctions, are actually detectable by identifying sudden concentration changes) and the extension of the map representation to the peculiar parameters.

2.2.4. TECNICAL AND ECONOMIC IMPACT

Even in this case, from the technical point of view, a first analysis does not seem to have any particular problems but, of course, a preliminary testing phase is necessary to highlight any critical issues.

From a purely economic point of view, the expenditure for extending the system, in addition to the aforementioned sensor costs, involves also the costs for some preliminary investigation and then the design of new macros that could result in a working load ranging from eight to ten man months, depending upon the use of a preassembled meteorological system or the developing of a customized system.

2.3. MONITORING AND MAPPING TRAFFIC CONDITIONS

2.3.1. GENERAL DESCRIPTION OF THE SYSTEM UPGRADE

The update of the traffic measuring and mapping system is aimed at the acquisition, storage and mapping of traffic conditions. This upgrade involves the use of dedicated sensors and the extension of the acquisition and representation software. Thanks to this update it will be possible to map the traffic information, to query the historical data, to see the evolution over time and carry out statistics and specific studies about it. In addition to the above, this feature allows a very important correlation between the traffic information and the related noise information.

2.3.2. HARDWARE UPGRADE

The non-invasive counting of vehicles is not an easy problem to solve as, by discarding the laying of bands on the asphalt, the vehicle counting is normally performed with very sophisticated and expensive radar doppler systems, capable not only of counting the vehicles but also of classifying them and to calculate their speed, length, etc. Unfortunately the price of standard system is in the range of thousand of euros. A cheaper approach, much less sophisticated and with limited information can use bluetooth technology.

Almost all cars are connected to one or more bluetooh devices due to the connection between the mobile phone and the car itself, as well as the availability of the function in almost all smartphones (often active). The main idea is linked to the possibility of using this function for an approximate vehicle counting system and to obtain information on the car

speed (time between "single device detected" and "device out of range") and presence of queues (same single device present for a long time).

Bluetooth is a standard cable replacement protocol designed primarily for low power consumption, with a short range based on low cost transceiver microchips in each device. Most commonly mobile devices are Class 2 devices that can handle a 10 meter connection. The Bluetooth protocol operates in the frequency range of around 2.45 GHz and, to reduce interference, divides the assigned band into 79 channels and switches between the channels 1600 times per second.

All this means that theoretically it may be possible to design a system capable of continuously scanning Bluetooth devices and then counting the unique ID number of the device to calculate the above mentioned parameters.

From the hardware point of view, implementing bluetooth system in the Dynamap system is not a big problem because many ready-to-use modules are available in the range of euros. Once again some electronic adaption, some enclosure and some firmware modification is needed.

2.3.3. SOFTWARE UPGRADE (INCLUDING ANED)

In order to implement a vehicle counter by means of bluetooth technology some practical problem should be solved and some deeper investigation are needed. One of the main problems occurs because there is no single relationship between the number of devices detected at a given time and the number of vehicles circulating at the same time: in fact, theoretically, the number of devices per car can be between zero and five (or more) and , in case of bus, it can jump to several tens. Some hypotheses can be made (for example, a sudden increase in found devices probably means "bus" and some hypotheses of correlation between number of devices with number of cars can be found on a statistical basis after some traffic measurements and "Bluetooth detection" on the specific place). In addition to the above, there is also the problem of separating the devices that turn in one direction from the devices that rotate in the opposite direction (perhaps even this can be solved by means of two detectors placed at a certain distance from each other, say one hundred meters).

However, it should be possible to find some solution to the aforementioned problems, but it is necessary to carry out a more detailed investigation and field test in order to verify how the vehicle counting can be derived from the Bluetooth detection.
The above mentioned problems can be addressed with a specific extension of the ANED algorithm to be developed specifically. The specific software should be able to identify, at least on a (solid) statistical basis, the number of devices that are part of the same vehicle and starting from this point it should be possible to compute the required parameters.

2.3.4. TECHNICAL AND ECONOMIC IMPACT

From the technical point of view, the main problems were already mentioned but a more deep preliminary testing phase is necessary to highlight these and possible other critical issues.
From an economic point of view, the costs for extending the system in this way, in addition to the sensor costs and its enclosure system, include the preliminary investigation and the design of the software that could be quantified in twelve-sixteen man months (first analysis).

2.4. OTHER POSSIBLE IMPROOVEMENTS

As specified in the previous action B2 the developed system is able to control, by mean of digital outputs, other types of external devices, such as giving orientation to a camera, or generally communicate in a bidirectional way by mean of standard protocols to any other kind of more advanced sensor.

2.4.1. MOTORIZED CAMERAS

The market offers many motorized cameras ready for use for external anti-theft applications. These devices normally use the Ethernet connection and therefore can be easily implemented in the system by an integration of the noise monitoring station firmware. The use of these devices may be more interesting when connected to a noise

direction detection system. Thanks to this feature it will be possible to obtain more detailed information about the measuring sites and traffic conditions.

2.4.2. NOISE DIRECTION FINDERS

Thanks to the use of additional microphones it is possible to implement an algorithm that identifies the direction of origin of the noise. This function becomes even more interesting when combined with the motorization of a camera that allows you to view traffic conditions remotely in a specific direction.

However, although in principle there are no important technical obstacles to the implementation of a direction identifier, the electronics of the monitoring station, as well as its firmware, would be heavily influenced by this implementation. The best approach would therefore be the creation of a dedicated device which should be coupled with the monitoring station, whose main role would be just managing pre-processed data coming from the coupled device.

2.4.3. FIRE DETECTORS

For fire detection, the market offers many commercial CMOS sensors with analogue or digital output, very low power consumption (generally a few μA) and very low prices (~1 euro). So the implementation of these sensors is quite simple and practically involves the aspects of fencing and wiring.

2.4.4. DYNAMAIC ROAD SIGN MESSAGES

Thanks to the possibility of the system to send signals correlated to the acquired or calculated data, an interesting extension deals with the possibility to drive variable message panels based on noise or air quality data (for example changing in speed limits can be automatically defined as function of noise and/or air quality; in the same way it is possible to open or close a lane or decide an alternative route).

Obviously all the above aspects are particularly delicate and involve different subjects specialized in the management of these problems, including traffic experts, administrations, police, etc. However, an extension in this direction, technically possible, certainly deserves to be investigated.

3. POTENTIAL IMPACT OF SYSTEM UPGRADE TO THE MARKET

The Dynamap system, interesting and innovative in its conception, has proposed itself as a tool capable of representing in real time the acoustic impact of road infrastructures in urban and suburban areas, also allowing to reduce the costs for the fulfillment of the Environment Noise Directive providing more accurate data.

Upgrading the system with additional parameters makes the system even more attractive for administrations, since it allows to achieve an overall view of the environment not limited only to the acoustic aspects, as well as for the end users (citizens), who are thus more involved in environmental issues.

In this perspective, therefore, the greater attractiveness of Dynamap due to the implementation of the new functions would certainly make it more appealing to potential users, and consequently this would lead to a diffusion of the system which could therefore be further improved and developed time by time with the support of all. In this regard, a possible development that joins the principle of open source shared development, with all its benefit, cannot be ruled out.

4. CONCLUSIONS

The development of the Dynamap system was certainly a good training ground for investigating possible alternative ways to tackle environmental investigation problems, generally expensive, with more limited economic resources and without the constraints of expensive proprietary licenses.

The development of the system, both in terms of hardware and software (database, geoportal, etc.) has also made it possible to check the implementation of other

environmental parameters, thus making the system more versatile for both institutional users and individuals citizens. The possible "extended" version of Dynamp, places the system among the tools for managing smart cities, that is a topical theme supported by institutions and citizens.

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