SADMAM – Combining Measurements and Calculations to Map Noise in Madrid

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Abstract [400] On Dec 29\textsuperscript{th} 2003, Madrid inaugurated their SADMAM system for dynamic noise mapping and automated calibration of noise maps. The main goal of SADMAM is to produce fast and cheap real (measuring) noise maps that represent both long-term and shorter-term levels including realistic propagation. This requires that the measurements be used to determine source strengths that are, in turn, fed into a prediction model that creates the noise maps. Through the use of mobile noise monitoring terminals, installed over shorter periods at strategic places, noise maps of smaller areas can be made and updated to be representative of the actual situation with for instance traffic modifications or special events. The paper describes the system, the concept of interaction between measurements and calculations and various aspects of the technique including the practicalities involved. Areas include integrating GPS, measurement data and GIS; integrating measurements in calculations to improve source model; calibration of multiple sources in a complex environment; and next steps.

1 INTRODUCTION & BACKGROUND

Madrid’s Environmental Administration runs the probably largest urban noise-monitoring network with attended and unattended terminals. A large amount of real data has been collected over the last 30 years or so and the City Council of Madrid has produced three urban city noise maps based on measurements. The last noise map of Madrid from 2002 was based on 4395 measuring points. Madrid City Council noise monitoring systems are based on several different databases with limited capacity for data management. The measurement-based noise map is very expensive and complicated to upgrade and data exploitation is limited and not user friendly. Madrid City Council needed an integrated solution, operative and functional to fulfill the EU Directive 2002/49/EC, dynamically upgrade Madrid’s noise map, integrate the several acoustic systems they have and avoid infrastructure and human resources problems.

2 THE SADMAM SYSTEM

The main goal of SADMAM is to produce fast and cheap real (measuring) noise maps that represent both long-term and shorter-term levels including realistic propagation. This requires that the measurements be used to determine source strengths that are, in turn, fed into a prediction model that creates the noise maps. Through the use of mobile noise monitoring terminals, installed over
shorter periods at strategic places, noise maps of smaller areas can be made and updated to be representative of the actual situation with for instance traffic modifications or special events.

2.1 The Concept

A noise map represents a stationary situation computed either with traffic input data correlated with real measured noise data, or a predicted situation based on assumptions about the evolution in the future. Therefore, it cannot be representative of the actual situation with for instance traffic modifications or special events. Madrid Environmental Administration, together with Brüel & Kjaer, decided to develop a new concept of getting and post processing noise data: dynamic noise maps - SADMAM (Sistema Actualización Dinámica Mapa Acústico Madrid). Of course, it is not conceivable to install thousands of noise monitoring terminals all over the city, but if you know the areas of interest, then you can zoom in more precisely by installing mobile devices at strategic places. For this purpose, Madrid invested in a system comprising: Noise Calculation Software Lima Type 7812, Noise Monitoring Software Type 7802 and several Noise Monitoring Terminals Type 3637A, and a GIS representation system, all tailored all together for this innovative application.

Data input

At the time of writing, 3 mobile monitoring stations are being validated in order to collect, fast, economically and accurately, time and space referenced samples of noise data. Each station consists of a Smart car fitted with a high-end Noise Monitoring Terminal Type 3637A, a Weatherproof Microphone Type 4184 on a pneumatic mast, to place the microphone at the recommended height of 4 m. a GPS (Global Positioning System) device to localise automatically the measurement position, and batteries for long term autonomy. A non-necessarily acoustically skilled single car driver simply positions the mobile NMT and data is collected every time the car is parked. Being small, the cars are easy to park in strategic places. Noise data are stored with its GPS location. Depending on the investigation, a number of mobile stations are parked over a period of some hours to some days.

Figure 1: Smart car mounted with noise monitoring terminal and example in use
Processes

State of the art communication ensures data transfer to the central server, the heart of the system. It has multiple roles:

- Collect attended or unattended measured noise data & other parameters
- Store raw data to ensure integrity of the system
- Manage input data for prediction, mapping and correlation between different factors
- Manage the database with all available information (raw and post-processed data)
- Manage post-processes:
  - Statistic calculations on measured data to determine algorithms for the evolution of noise function for specific periods and areas
  - Statistic calculations based on long-term data from the permanent NMT network
  - Prediction algorithms using Lima and Predictor
  - Tools for outputting results
- Outputs for reporting and communication (e.g. on the web)

As all data are geographically referenced, they will be integrated with GIS (Geographical Information System) and GIS data such as topography, urban details, population, weather, etc.

2.2 Integrating GPS, Measurement Data and GIS

A GPS interface has been implemented as standard in the Noise Monitoring Terminal Type 3637. The GPS position is logged 4 times a second and stored. Then, for every hour of measurement data, the position of the terminal is determined from the average of the logged GPS positions. This is more accurate than the method described above. When the measurement results from the terminal are downloaded to the central server software, it identifies if the terminal has moved (if a maximum change in position limit has been exceeded - e.g. 4”, equivalent to ca. 100 m in Madrid). The position is then automatically plotted on a map of the site and changes in position of the unit are also automatically identified.

Figure 2: Automatic identification of position of noise monitoring terminal achieved by GPS logging

3 INTEGRATING MEASUREMENTS IN CALCULATIONS

“Real-time” local calibration: means that the relevant measured data are collected and safely stored by the noise monitoring software. Representative values for a specific period in a specific geographic area are then transferred to Lima in order to adjust the emission levels of user-defined sources so that the resulting map better matches the actual situation. Depending on the complexity of the area to be mapped, the calculation over a section of the city can be done in few hours. Thus, for example, the daily measured levels around a local road infrastructure can be used to make maps of the daily variation of the noise contours in this area. With knowledge of the diurnal variation of the noise levels measured close to roads, $L_{DEN}$ and $L_{Night}$ parameters can be determined, with acceptable accuracy for strategic noise maps.
The Principle

Noise monitoring data can be used to determine source levels of roads in an acoustic model of an area. For a simple source-receiver combination:

\[ L_{p,A} = L_W + A \]  

(1)

Where:
- \( L_{p,A} \): equivalent sound pressure level at the receiver (measurement) point
- \( L_W \): sound power level of the source (road)
- \( A \): attenuation between the source and receiver (e.g. distance, screening, reflections)

This means that if one knows the level at the receiver point, the sound power of the source can be determined. Once this sound power level is known, levels at other points can be calculated using standard propagation algorithms.

However, if there are several sources, the sound power levels of the various sources become more difficult to determine. However, with some knowledge of the behavior of the different sources and through careful choice of the receiver positions, even this problem can be solved. A typical urban area is shown in the figure below. The roads are classified into major roads (thick lines), medium roads (medium lines) and minor roads (thin lines). These roads run through built-up areas and are, thus separated by high buildings. This reduces the noise propagation from one road to another.

Measurement positions are indicated by the green circles:

- **Position A**: The noise at this point is dominated by the major road. No other roads influence the levels at this point. Thus this point can be used to determine the source emission of the major road.

- **Position B**: The noise at this point is dominated by the minor road. No other roads influence the levels at this point. Thus this point can be used to determine the source emission of the minor road.

- **Position E**: The noise at this point comes from the major road and the minor road. This point can be used to verify if the emissions of the major and the minor roads.

- **Positions C and D**: The noise at these points are dominated by the adjacent medium road. Even if the noise is influenced by the major road or the minor road, the emissions of these are known and the emission from the medium road can usually be determined. If the traffic flow on both roads is very similar, then the levels can be used to further optimize the emission of the roads.
Reverse engineering can determine source emission levels from proximity measurements. The green circles are measurement positions. The brown lines are roads whose traffic intensity is indicated by the thickness of the lines.

In principle, the number of sources whose levels can be determined is equal to the number of measurement positions used. However, the number of sources to be determined can be increased by creating relationships within the sources and by grouping them (up to a current limit of 16 groups in Lima). Grouping of sources also permits “real-time” adjustment of noise maps dynamically linked to input data (e.g. for simple updating of a noise map with limited recalculation required).

The complexity of the acoustic environment (number of contributing sources, shape of the buildings around the source-receiver area) determines how accurately the source emission can be determined. The accuracy of the source emission determination declines as the complexity of the acoustic environment increases. This can be countered by increasing the number of measurement positions available to determine the source emission. Thus, if a calculation or measurement position is subject to several sources determined in a complex acoustic environment, it too will be less accurately modelled.

In the future, Lima can be set up to use this factor to determine tolerances for the different measurement positions. Receiver (measurement) points can be classified, e.g.:

1. Receivers close to one dominant road source with simple noise environment (low complexity, high accuracy)
2. Receivers close to several road sources with simple noise environment (medium complexity, medium accuracy)
3. Receivers close to several road sources with complex noise environment (high complexity, lower accuracy)
And result tolerances for each class identified. The user then adds this tolerance to the receiver object attributes.

![Image](image1.png)

**Figure 4: Example where maximum and minimum levels are set to 59 and 49 dB, respectively (i.e. 54 ±5dB)**

### Implementation in Madrid

Madrid has an existing database of historical noise levels, spaced at regular intervals. These could be analysed to add suitable tolerances for determination of source emission (see Figure 5):

![Image](image2.png)

**Figure 5: Measured levels from existing noise map with estimates of uncertainty of the resulting source estimation**

The levels can be imported from the database into Lima through some defined format. Provided the positions can be identified, the levels can be added to receiver points at the correct positions. Lima can also help to add the tolerances to the measurements by analysing the number of sources within a certain radius of the receiver point.
Once this is done, Lima then calculates the emission levels. In addition to the tolerances for the receiver points described above, tolerances on the sources (roads) can also be added. This allows the user to define minimum and maximum emissions and, thus, keep traffic flows within reasonable limits (see Figure 6).

Figure 6: Example of fixing quotas within minimum and maximum emission levels. This method is similar to the one described in the text.

By limiting the maximum distance between source and receiver for calculation (the fetching radius), the calculation speed for this activity is optimised.

4 NEXT STEPS

New wireless communication modes, computation speed and fast Lima calculation core make it possible to create noise maps over a large scale in “real time”. Geographically referenced measured data from the mobile NMTs are used for “locally” calibrating calculated maps. The key point is the interdependency between measurements and calculated values for high quality output results in the environment over time and space. This will allow Madrid to efficiently validate and improve the quality of their strategic noise maps that will form the basis of the action plans required in the EU Noise Directive 2002/49/EC. Public confidence in the maps will be growing up and unnecessary actions based on incorrect results will be avoided. In addition, the dynamic mapping will help Madrid to improve the quality of life for their citizens and visitors alike.

5 SUMMARY

The main goal of Madrid City Council’s SADMAM system for dynamic noise mapping and automated calibration of noise maps is to produce fast and cheap real (measuring) noise maps that represent both long-term and shorter-term levels including realistic propagation. This requires that the measurements be used to determine source strengths that are, in turn, fed into a prediction model that creates the noise maps. Through the use of mobile noise monitoring terminals, installed over shorter periods at strategic places, noise maps of smaller areas can be made and updated to be
representative of the actual situation with for instance traffic modifications or special events. The paper has described the system, the concept of interaction between measurements and calculations and various aspects of the technique including the practicalities involved. Areas covered include integrating GPS, measurement data and GIS; integrating measurements in calculations to improve source model; calibration of multiple sources in a complex environment; and next steps.

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