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MOBILE NOISE SYSTEM ARCHITECTURE

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Abstract
MobileNoise is a prototype web application designed for the collection, processing and publication of noise data measured primarily using mobile phones. It is divided into three main parts. First module is used to communicate with remote noise sensors and storing the measured data. It uses the Sensor Observation Service interface and Observation & Measurements standard for communication. This application is designed especially for communication with smartphones equipped with customized NoiseTube mobile application. The second module classifies and generalizes collected data. Based on these data probable noise levels in the exposed areas at given times and their estimated accuracy is calculated. The third module allows the visualization of measured and generalized point, line and surface data in form using raster tiles, along with other spatial data.

Keywords: *environment, noise, environmental noise, Sensor Observation Service, generalization, smartphone*

INTRODUCTON

Noise is one of the biggest polluters of the human environment in Europe. According to European Commission, approximately 125 million people in the EU is affected just by noise from car traffic at equivalent levels higher than 55 dB. About 8 milllion EU inhabitants suffers due to noise from train operations, and air transport has in terms of EU noise impact to around 5 million people. [7] Thus road transport is becoming the biggest polluter of the human environment in the EU. [8 p. 18] European Union adopted a very comprehensive plan to combat noise from road traffic, which includes the acquisition of geographic data on areas and population affected by noise and the planning and implementation of corrective steps (ie. Strategic noise maps and action plans), which are in competence of individual member countries. [9] However, effective implementation of noise reduction provisions go right especially around the main roads outside urban areas, but more than 2/3 of all the noise-affected population live in urban areas [8 p. 24]

Measurement and evaluation of number of people affected by noise from surface transport is very problematic, especially in urban areas, where local diverse characteristics of the noise environment (configuration of buildings, greenery and street furniture greatly affect the absorption or reflection of noise from various noise sources) does not allow to perform easy and long-term measurements for larger areas and therefore, in most cases, is necessary to model the data from computation. It also is quite difficult to determine the actual rate of people affected by noise because people are moing throughtout the city from different reasons.

In the context of new technologies, such as smart mobile phones, it is possible for measurements with sufficient accuracy to be performed by the citizens themselves. Although measurement produced by a common citizen using standard mobile phone cannot be understood as a full replacement of measurement by qualified personnel using certified sound level meter, from a sufficiently large number of measurements carried out by educated people is possible to obtain good quality data. From that kind of data is then possible to perform basic analysis of received dozes of noise and also the geographical distribution of the noise [3]. However, to be possible to relate the measured data with the problem of line noise sources in the urban environment, it is necessary to get the city street network into account.

One of the main tasks of hereafter introduced system MobileNoise was to test the suitability of different approaches to transform the measured noise data (both from mobile phones as well as from other platforms) to the noise model, which sufficiently and appropriate represents an urban area, and to demonstrate the possibilities represented by this model, using several basic spatial and temporal analyses and classifications.

Street network as a necessary basis for data processing noise from road traffic

Typical European city is, among other, characterized by the need to spatially organize the surface transportation. In cities, lanes for cars are usually reserved in the inner part of the streets, while pedestrians are often moving around the edges, on the sidewalks. Since passing cars can be understood as a line noise source, a noise measurement is possible even if the sound level meter moves along a given line during measurement in roughly same distance. If there is not any obstacle between the noise meter and the noise source, it is possible to apply the measured value to the entire homogeneous line segment, naturally after corrections corresponding to a distance between them.

One of the biggest problems of this approach is the use of a mobile phone with a GNSS receiver (eg. GPS, Glonass, etc.), especially the uncertainty in determining the position. The urban environment has a significant influence on the strength and the path of the radio signal. Variations in the order of ten meters or more may be recorded, however, on average, in the urban environment the mean spatial deviation ranges to about 2 - 5 meters. [3, 12]. This spatial precision can have following impacts:

1. Due to the nature of the dissemination of environmental noise in the city it is often not possible to estimate noise levels around the measurement point sufficiently and accurately. Given that the sidewalks are often positioned in close proximity of roads, a spatial error of the 5 m from the roadway can cause erroneous assignment of the noise level by about 6-10 db [4].
2. In the case of higher random errors (eg. due to the so-called street canyon or tall buildings effect) measurements may be systematically assigned to another source (street) for given area, which may indicate inadequate allocation of noise pollution for both sites.
3. Measured imprecision is negligible in the direction parallel to the axis of the street, but only if the behavior of the noise source in this axis is homogeneous. In the case of sudden changes (intersection, threshold etc.) an error may occur also here.

Given that more accurate systems for determining the position is still not sufficiently developed and implemented, position information must be refined by the user and data processing system must be able to transfer such data and take them into account during processing. Due to the characteristics of pedestrian movement in the urban environment it is appropriate to record , at least, if the user turns (changes the direction of the street or road), or whether she enter the street or leave it.

Another problem may be an asymmetrical street noise situation in relation to their longitudinal axis. Reasons for this asymmetry can be both a greater traffic flow on one side or various obstacles that affect the noise situation around (eg. cars parked on one side of the street). Also sidewalks can be at different distances from the communication axis. For this reason, it is appropriate to record the side of the street, which often requires user intervention again, especially on narrower streets.

MOBILE NOISE SYSTEM

Introduction of the system

MobileNoise system is a suite of applications, whose main tasks are:

1. Collection and storage of environmental noise data, primarily from measurements carried out through mobile phones, but also from other sensors, both networked and individual.
2. Processing and analysis of various forms of such noise data
3. Visualization of data and analyses
4. Accessing data and analyses for additional electronic processing or visualization

The main operational objective of the application is to enable continuous processing and web presentation of noise data above the entire city of medium or larger size, or seamless processing and visualization of larger areas.

For these reasons, the MobileNoise system is divided into three separate modules that perform similar tasks:

1. Module for recording noise levels of in situ measurement and additional parameters using smart mobile phone.
2. Module for importing, storing and exporting of noise and derived data from and into an open format using the Open Geographical Consortium standard.

3. Module for processing and visualization of noise data using a web interface.

As seen from the above, the emphasis is placed on already available and widely used standards. The implementation itself is trying to utilize existing widespread open solutions, which greatly increases the portability of the system, enhances its efficiency and reduce development costs of existing solutions. The main benefit of this system is primarily

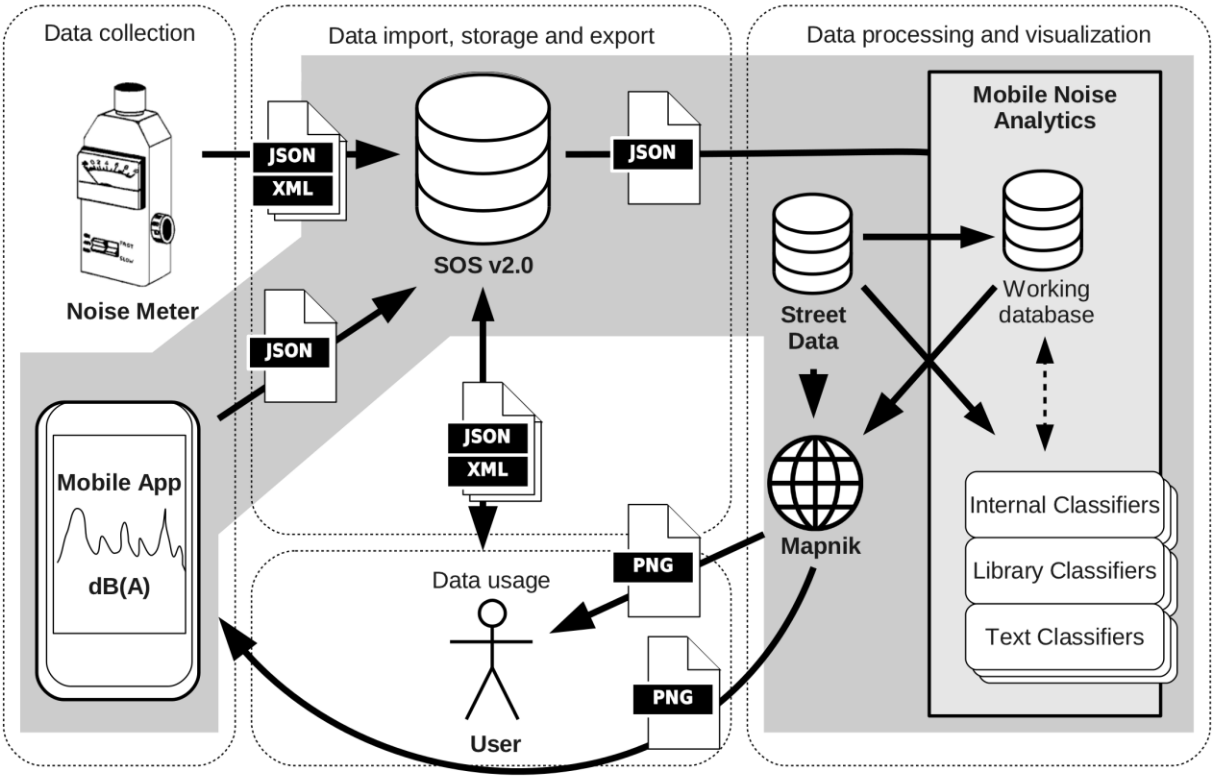

Figure 1. Schema of MobileNoise system and its surroundings. In gray area is MobileNoise system itself. More description in text.

modifications and orchestration methods of the individual parts; and also analysis (classification) modules, which are adapted for processing (serialization and classification) of noise point data to the linear and raster space. General schema of MobileNoise system is on fig. 1.

Mobile platform for measuring noise

The basic source of thematic data, considered for the MobileNoise system, are measurements of sound levels using a mobile phone microphone. The output from this device, if is appropriately calibrated, is achieving precision comparable to certified level meters (± 1 dB) both in the laboratory and in the field [19, 20].

For this reason, as the base platform for mobile noise measurement, already proven open source mobile application NoiseTube was selected, tested and modified. Source code of this application is freely accessible and licensing terms allows modification of the application for research purposes. [17] This application evaluates the amplitude of recorded acoustic tracks by mobile phone's microphone and using Riemann sum gains equivalent sound pressure level (L_{eq}) for fast sampling (which is 1 second), which is further adjusted by the weighting filter A (L_{Aeq}). The resulting data can then be compared with outputs from the classic sound meter [18].

Adjustment of the module consisted mainly of:

1. Modifying the data model, adding the ability to identify the movement of person in the street network,
2. Associated adjustment of the graphical interface by adding buttons to identify the relative position by the user,

3. Replacing of the Google Maps view by map view displaying custom tiles with the street network from database. This view is necessary for correct identification of the relative position of the user relative to the road network database available in the analytical module (see chap. Analysis Module),

4. Adding a Open Geospatial Consortium (OGC) sensor data standardized protocol for communication and data storage: Sensor Observation Service (SOS) [16] encoding and Observation and Measurement 2.0 (O&M) [14] protocol in format of JavaScript Object Notation (JSON). The module is still able to communicate with the NoiseTube server (from where it can download calibration data and send measured noise data), and also with a standard OGC SOS server.

The module is written in Java, which increases its portability to other platforms, but limits its computing power to some extent. It is therefore not appropriate to incorporate any further data processing into this module. Mobile phone behaves as a fully programmable mobile network sensor with a standardized digital output.

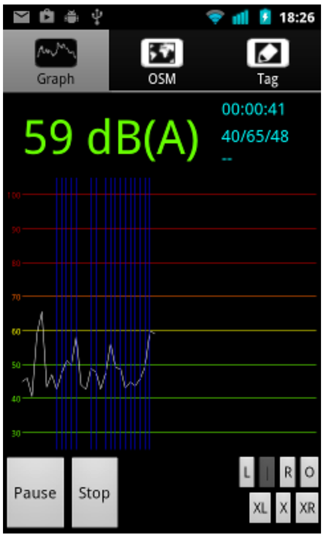

Figure 2. Measuring screen of MobileNoise noise meter application for smart phones. On the right side are buttons for setting position in street network: Upper row sets position on the street (left, center, right, out of street), lower row sets behaviour on crossings (turning left, going straight, turning right). On the left side are buttons controlling measurement itself. Blue lines indicates assigned metadata information.

Working with mobile application

User after signing up (currently there is no need to enter the name or password, only device identification string is registered) and uploading calibration XML file from the NoiseTube server recording of sound pressure levels can start. Furthermore it should be a little longer than the GNSS receiver evaluates position of the instrument the signal. Then the user can go. It is however necessary to keep the device's microphone away from the user's body.

When moving throughout the street network, user can enter change of walk direction or street using the buttons on the screen. This task is quite difficult in normal city traffic because the user must check the direction of the microphone and also he must monitor the situation around. This difficulty can be solved by an external microphone, but this solution requires a custom calibration. After measurement (or during, if it is long enough), data is sent over the Internet to a server, or stored in the internal memory to manual upload.

The layout of controls on MobileNoise screen (see fig. 2) in currently not adapted according to ergonomics and user experience, as this field has not been examined. Adjustiement of the interface should come in the next step in connection with testing of the noise measuring gamification concept.

Import, storing and export data on noise

One of the goals of the MobileNoise system is provide easy and standardized access to the measured and processed data. The currently most widespread and universal open standard for the transfer and storage of sensor data with a geographic component is Observation and Measurement 2.0. [14] Using this standard one can record basic information about measured values including coordinates and other associated parameters.

As the transport and communication protocol can then be used the Sensor Observation Service version 1.0 or 2.0 [16], which works as an API layer over the HTTP protocol. This protocol addresses both the registration and identification of individual sensors (using language Sensor Markup Language [15]), as well as communication between the source of sensor data and the user. The user can be both a database for data storage and application processing and visualizing this data.

1. The current reference application for SOS 2.0 [1] has many limitations (not entirely satisfy the relevant standard), eg. it does not allow direct integration of mobile sensors, since it does not reflect a change in their position in the respective metadata. However, these restrictions can be circumvented so that position data is sent in the form of sensor data, and then postprocessing can store this data for that record as metadata, so it should be possible to perform spatial queries also over mobile data.
2. It does not allow upload large sensor data files at once (co called result) for different profile configurations of the same equipment, but always only a uniform structure for all devices of one type. For this reason it is necessary to send each data as separate observations. The data can then be synthesized using postprocessing up in the database.

This reference application was therefore, contrary to the original intent, used only as a communication module for receiving data from mobile phones and other sound meters, and as the primary repository of raw data and individual results of analyzes, intended for publication. Analytical applications can download the data forth and back from and to the server in the format of Observation and Measurement using Sensor Observation Service.

The reference application is written in Java as a servlet for Apache Tomcat environment and as a storage uses PostgreSQL database with PostGIS extension. Application have, by the author's experience, significant problems with proper work under GNU Linux operating system, so it is necessary to operate it in the Microsoft Windows environment.

Noise data processing

The main part of the system is a module for processing the noise (or other sensor) data bound to the street network and urban environments in general. Application allows:

1. Upload data from sources of SOS version 2.0 according to specified parameters,
2. Save the data to a temporary or permanent database,
3. Make 2D spatial analysis over street networks stored in the database, over a grid or free space
4. Export computed data back into SOS version 2.0.
5. Visualize data and results via simple web interface.

The module was, due to computational complexity and portability, written in C++. The underlying database can now use PostgreSQL with PostGIS extension, but it is possible to extend it over other database systems. The module can be controlled from the command line using the setup files. User analysis is also possible to modify by files using the PL/SQL language. Theoretically, the application can be configured using the Sensor Process Service [13], which would allow to control the application remotely larger community. However, this option has not been widely tested.

As stated earlier, the main operational objective of the application is to enable continuous processing and web presentation of noise data above the entire city of medium or larger size, or wider seamless area. The following subsections describe the basic workflow of the application.

Communication between module and SOS

The first part of the module's workflow is download the required sensor data from the SOS service. Configuration of downloading is done from the command line or based on the configuration in the configuration file. Usually, the noise data is downloaded according to the specified space and time limitations (usually the data stored since the last download). Communication with SOS takes place via JavaScript Object Notation (JSON) messages and information about the location, noise levels and position relative to the street network are downloaded separately. Data are continuously stored during download into a working database.

Street data model

To work with a model of the city a data model which defines the street network is crucial. The main reason is that the reference points are bound on this street network. As sufficient for testing purposes appears to be using OpenStreetMap open data. Using such data without prior checking is not possible because the average spatial error in densely and well-mapped areas may exceed 5 m [10] and above data may suffer from incompleteness [2]. However, in the test area (selected parts of the city Brno in the Czech Republic), the spatial error does not exceed 1 m and the data can be considered, after the inspection, as complete. There is also possibility to import any other data, but the resulting database structure still must correspond with OpenStreetMap data. Relatively important part are also data about the sidewalks, which can greatly refine certain analyzes.

Analysis module

Analysis module is the basic module processing noise data. The basic mode of this module is to work with line street model. As a supplement it can also use raster logic. Analytical module consists of a preparation, calculation and export parts.

Data preparation

Preparatory part in a typical analysis work cycle over the line data usually has the following schema:

1. Uploading a predetermined portion of the noise data, determining spatial extent and affected streets.
2. Detection of individual series of noise data (coherent sequence of measurement points and values from one device representing successive measurements) if this information is not provided.
3. Correction of positional information of each measurement record.
4. Initialization of reference points (on lines or in raster). In this section are initialized, traced and (re)indexed reference points for the street network and calculated their orientation. The goal is a representation of the cellular structure of the street network.
5. Association of the individual measurements on individual reference points of the street network and determining appropriate street, street side or path, which allows to classificate data by line properties.

In case of raster data, they may be easier to prepare: E.g. the data are sequentially clustered to an individual cell directly, according to their recorded positions.

Data analysis

Analysis of the data in the system is performed by specific modules called Classifiers. Currently, classifiers can be divided into three groups:

1. Basic classifiers: These classifiers are designed to perform basic analysis and classification tasks of a noise situation, such as aggregating data, calculating averages and uncertainties on the lines etc. They are an integral part of the application. These classifications can be expanded by writing new classes derived from the base class.
2. Library classifiers: User can connect a dynamic library with prescribed interface in C or C ++, which contains the classification algorithms (currently only for Windows or Linux).
3. Database classifiers: User can upload PL/SQL language commands in a text file.

Individual classifiers can also be orchestrated. Configuration of individual classifiers and their orchestration is possible using a configuration file in JSON format, or from the command line.

Example of a basic analytical task

Fundamental analysis, which is part of the application, have a task to produce data on noise pollution in the streets. This data should be suitable to visualize. An example of such analysis is the calculation of noise levels in a certain street and uncertainties for the calculated levels. The procedure of this analysis is as follows:

1. For each reference point is calculated the average noise level for a specified period and the time of day. This calculation is performed as a weighed average all the measured values appropriate for a given reference point (cell) from space and time perspective. The weights are determined by temporal and spatial distance from the desired point.

2. For each reference point is then calculated the average level of uncertainty for a specified period and the time of day, in a similar way as above in the point 1.
3. The points on the line with values falling into the same (preset) intervals are aggregated into line.
4. The relevant lines are exported to the database so that they can be provided as data to the SOS, or for visualization.

Further analysis and classification steps can be performed on this data, both in the orchestration or without.

Visualization of noise data

Visualization of data measured or calculated by the system is done using the Apache web server and raster tile service Mapnik. This service was originally developed for visualization of data from project OpenStreetMap, but is useful for visualizing any geodata.

Apache server is primarily used for visualization of the street network for the mobile part of the system. Also, it is possible to use it for calculated data visualization and for production of street noise maps. Visualization of raster maps using Mapnik is limited, however, after proper data conversion (for example, by classification modules) it can also display raster data. The application user interface consists of JavaScript module called Leaflet.

Visualization settings (e.g. color, thickness and texture of the lines) is possible via a Mapnik special configuration XML file [11]. This file can be created, for example, in TileMill, which can work as a WYSIWYG editor.

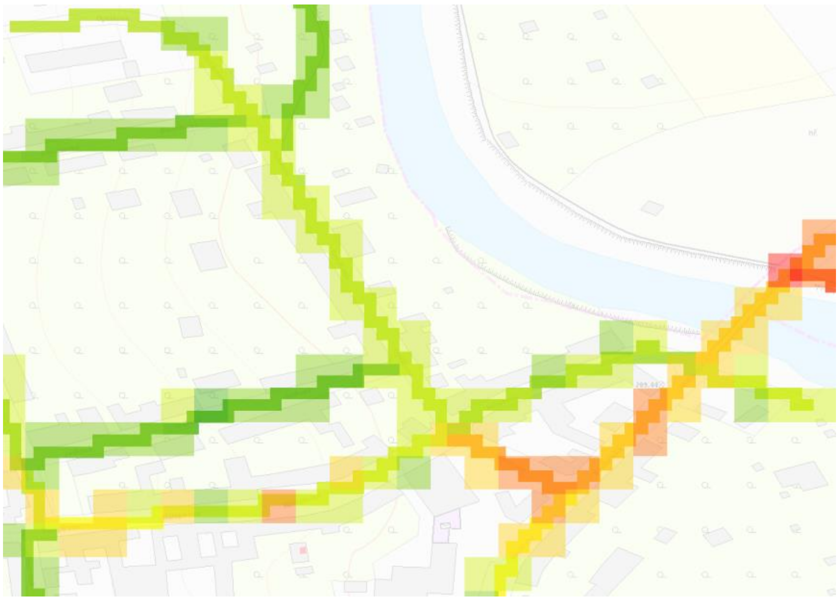

Figure 3. Visualization of determination of homogeneous street segments using regular raster data

CONCLUSION

In the field of processing of environmental noise currently predominates using a regular square grid. Given the relatively large spatial inaccuracies, which limits conventional GPS receivers, there must be relatively large cells (minimal rim size of about 7 m for data clustering [5]), which in case of irregular street network in cities significantly increases the uncertainty of generalized data. Usage of this data in further analysis is therefore limited.

System MobileNoise tries to overcome this limitation by systematically mapping the measured data to the street network. This system has been designed to handle a comprehensive range of operations associated with noise data, from collection, through processing, preservation, access, to data visualization of noise, particularly for surface transport and urban areas. To fulfill this task it uses a variety of available applications, which are orchestrated into a functional unit. The core of the system is a newly developed module, allowing classification and analysis of noise data at both regular and irregular street networks of typical European city. This module is expandable for additional functionality in both compile-time and also at run time.

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