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Article

Conceptual model of noise monitoring system for construction projects in cramped conditions, based on sensors and GIS

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Abstract. Existing sound measuring equipment are mostly designed for indoor use, and those of outdoor are costly and demands human involvement multiple times. This study proposes the concept of a compact and cheap sensor and GIS-based system that runs algorithms of sound distribution and visualizes interpolated and extrapolated data as heatmaps in an interactive map. According to the concept, the system consists of several noise measuring devises wirelessly connected to a data collector that transmits the measurement data real-time through internet to a server, where the data is analyzed and visualized. The integrated into GIS algorithms are designed to identify the sound sources and locations where the sound level exceeded its daytime or nighttime standard limits. The implementation of proposed concept may make noise issues related to construction activities more transparent.
Keywords: acoustics, construction noise, monitoring, sensors, GIS.

1. Introduction

Construction noise can be considered as one of the most annoying phenomena for the residents of nearby buildings. This is an important aspect that must be taken cared of during any kind of cramped construction in urban area [1], since its certain levels can have a negative impact on the surrounding environment and human being. These levels are characterized by the Sound Pressure Level (SPL) arising at certain point, the tolerant ranges of which are described in [2-3]. SPL (L_p) is classically measured in Decibels (dB). The so called “loudness” that human perceives is highly related to SPL, sound frequency and duration [4], and may be measured using “equal-loudness contour” (Figure 1) when the constant loudness is perceived [2].

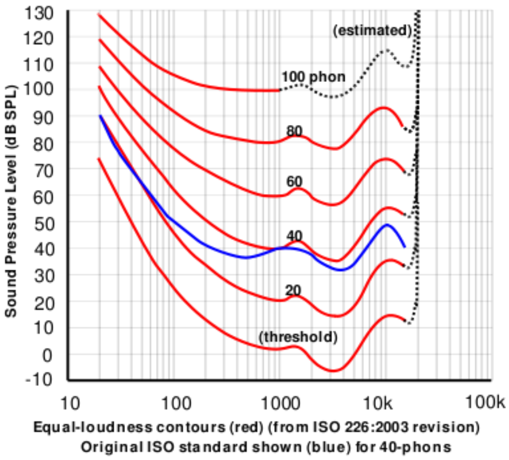

Figure 1 – Equal-loudness contours with frequency in Hz [2]

Depending on SPL the noise affect human variously. For example, a noise level of 20-30 dB is absolutely harmless, without which human life is impossible. Noise around 60 dB can be annoying, and 65-80 dB can have physiological effects. Noise level more than 85 dB leads to disorders of hearing organs. The level of noise more than 120 dB can have mechanical impact on the whole body of human, and at 130-150 dB a pain threshold is reached [5-6]. The permissible levels of noise in residential and public buildings, as well as surroundings of urban areas under construction are regulated by local sanitary rules and norms, and hygienic standards of each country. In Kazakhstan, for example, the general noise standards are regulated by [7] and controlled by [8]. Some types of economic activities are regulated by specific requirements for the level and nature of noise, for example [9]. According to these standards, the noise level at day and night should not exceed 55 and 45 dB respectively. For the registered violations of the established noise limits, there are administrative penalties and fines [10].

Unfortunately, there everywhere many cases of the violations of noise limits during the construction [11-12]. However, it is possible to question the evidence of certain cases of noise violations by construction organizations, despite the fact that due to complaints from the neighbors these organizations had to pay large penalties in order to avoid delays in the construction process. Most likely, such scenarios occur many times due to no specialized equipment is used for monitoring and registering noise pollution in and around the construction sites. Modern acoustic monitoring systems propose a variety of functionalities and a great quality, but majority of them are built for indoor use and may be unaffordable for small scale construction project budget. Outdoor ones mostly measure noise for short-term at certain point where they are located and are also costly [13-14]. Absence of continuous visualization or real time mapping of noise pollution without human or desktop software input is another disadvantage of existing systems [15].

Considering that currently used acoustic monitoring systems are costly and still do not fully cover the needs of cramped construction in urban areas, this study is aimed on structuring the concept of an easy-to-use and affordable system for real-time monitoring of noise level in construction sites.

2. Methods

To structure the concept of urban construction noise monitoring system the following aspects are consistently considered: specifics of construction in cramped conditions; regulatory support; nature of noise distribution and related parameters; functional architecture of the system; sensor capabilities and mechanism; sensor allocation strategies; and visualization techniques.

The SPL is calculated as following [16]:

$$L_{p_i} = 20\log_{10}\left(\frac{p_i}{p_{ref}}\right) = 10\log_{10}\left(\frac{p_i}{p_{ref}}\right)^2, \quad (1)$$

where: p – sound pressure (Pa); p_{ref} – reference pressure, 2×10^{-5} Pa.

Since the majority of noise in the construction site have no direction [17], the sound there takes a spherical nature. According to [18], the sound pressure measured in a certain distance (d) from the spherical sound source decreases by $1/d$, which is called an "inverse-proportional law". From the latter it follows that having the sound pressure at one point located at a certain distance from the sound source, it is possible to calculate the sound pressure at any other point knowing the distance from it to the sound source:

$$p_{i+1} = \frac{d_i}{d_{i+1}} \cdot p_i, \quad (2)$$

where: n – ordinal number of a point, where the sound pressure d is measured.

The inverse-proportional law also states that the SPL at any point can be calculated based on any other point if the distances from these points to the sound source are known:

$$L_{p_{i+1}} = L_{p_i} + 20\log_{10}\left(\frac{d_i}{d_{i+1}}\right), \quad (3)$$

As mentioned by [17], the noise in construction site may be produces simultaneously at several locations with various SPLs. Therefore, an accurate detection of the sound source location and measure of the sound pressure there in-time and simultaneously is almost impossible physically. To solve this task this study proposes to assume that the points with known values of sound pressure (i.e., those where the SPL is measured) are equivalent to those of sound source; so that the inverse problem is considered. In this case, assuming that the sound waves are distributed from the measured points, at certain distances in-between these waves somehow collide where a particular rule or equation should be used to determine the combined SPL multiple sound sources (i.e., measured points). In this case a sum of SPLs is taken as:

$$L_{p_\Sigma} = 10\log_{10}\left(\sum_i^n \left(\frac{p_i}{p_{ref}}\right)^2\right), \tag{4}$$

From the Equation 1 and basic logarithmic rules derived:

$$\left(\frac{p_i}{p_{ref}}\right)^2 = 10^{\frac{L_{p_i}}{10}}, \tag{5}$$

Therefore, when combining Equations 4 and 5 we find:

$$L_{p_\Sigma} = 10\log_{10}\left(\sum_i^n 10^{\frac{L_{p_i}}{10}}\right), \tag{6}$$

For the considered case Equation 6 can be used for determining the SPL at intermediate points where multiple sound waves are collided.

The functional architecture of the system includes activities taking place outdoor and indoor, as well as those of both (Figure 2).

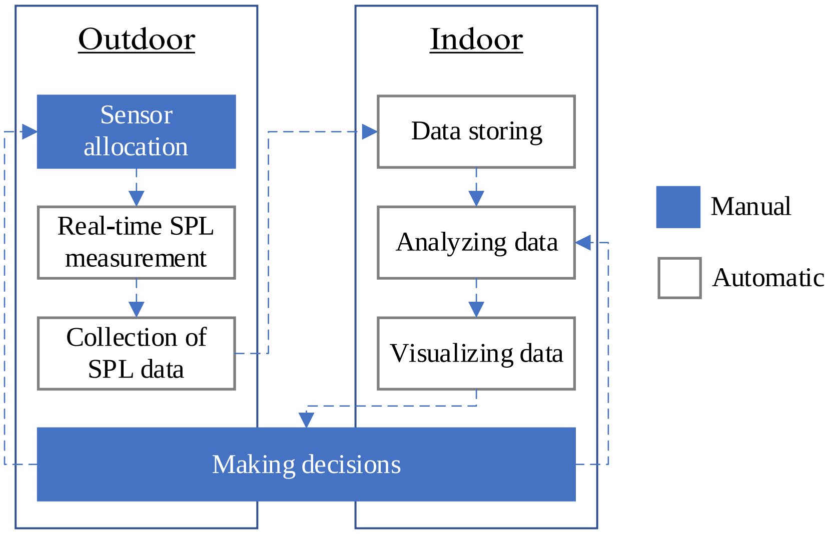

Figure 2 – Functional architecture of the system

As shown in the architecture above, majority of processes are performed automatically. This becomes possible with a combination of various components, such as electronic devices, wireless technologies, cloud storages, different algorithms, and online user interface. Manual work is reduced to a minimum to reduce human error, increase accuracy, and save time and resources.

The system should detect and record the events of noise limit violations, visualize locations where certain event happened and when happened, as well as present real-time SPL values at any point of construction site and nearby buildings.

Based on the experience of previous experience [19-20], for each construction site there should be two types of electronic devices: several measuring devices and a single data collector. Communication between these devices must be provided by small-sized wireless technology, working at distances corresponding at least to the dimensions of the construction site. Experience on similar studies [21] show that the wireless technology “Lora” perfectly meets such demand.

Since the construction site is characterized by its own chaos, where machines, mechanism, and workers are always in action, the measuring device should be also transportable, easy to recognize, handy and lightweight, as well as rigid when installed for certain reasons, such as: to avoid damage due to heavy equipment movement, to quickly locate and relocate, as well as to ease installation. For such specifications, the most suitable device design appears to be a vertical rod with a pin at the bottom and electronic components at the top. Electronic components should be put into the rugged housing and include at least microcontroller, battery, Lora module, and microphone sensor. The measuring devices should be allocated to the construction site based on certain strategy, taking into account surrounding features and their positions (e.g., existing infrastructure and neighboring buildings).

The data collector should have a housing, microcontroller, both rechargeable battery and 220V power connection, Lora module, USB slot, memory card, and internet module. It should continue working for some hours even when not connected to 220V without loss of collected data.

The system should include also a server-side containing a database and web application to store, analyze and visualize data received real-time. Analysis made real-time should be based on the algorithms of SPL estimation, as well as interpolation and extrapolation techniques.

3. Results and Discussion

Figure 3 below presents the concept of noise measuring device.

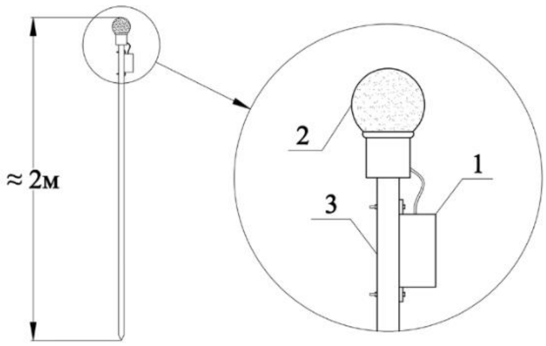

Figure 3 – Concept of noise measuring device

The proposed concept of noise measuring device consists of three main parts: housing (1) where majority of electronic components are located; microphone sensor (2) attached to the top; vertical rod (3) with a pointed end, where all components are fixed. The rod must be made of corrosion-resistant metal, preferably aluminum, to withstand harsh weather conditions. It is expected to be driven into the ground to a depth sufficient to hold it firmly in a vertical position.

The schematic concept of electronic devices of the system is presented below (Figure 4).

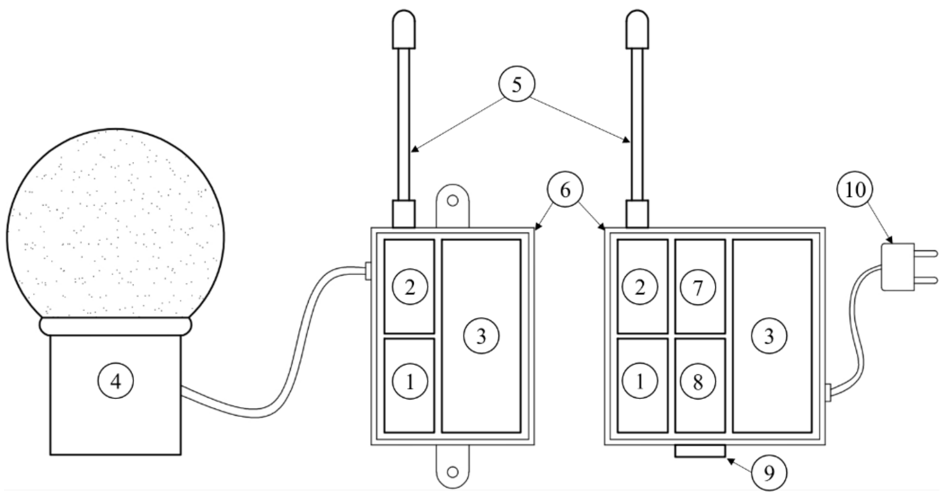

Figure 4 – Electronic components

According to the Figure 4 above, the electronic components of the system include: microcontroller (1), Lora module (2), battery (3), microphone sensor (4), antenna (5), housing (6), internet module (7), memory module (8), USB slot (9), and 220V plug (10).

The server-side of the system proposed can be constructed using phpMyAdmin or pgAdmin running the MySQL or PostgreSQL relational databases. The web GIS application can be constructed using OpenLayers opensource Javasript API, or commercial version of Leaflet Javasript API. The general concept of the GIS application performance is presented below (Figure 5). The presented picture was constructed using opensource application called FNM [22].

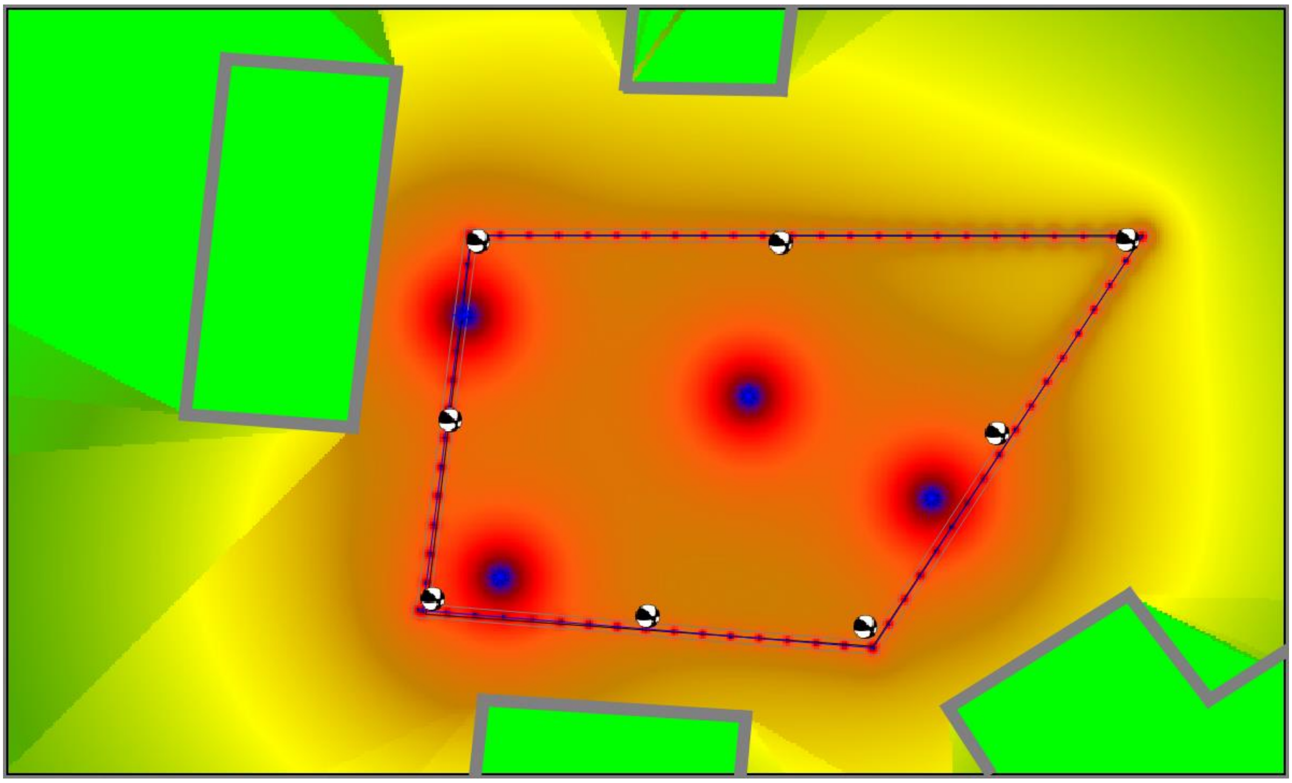

Figure 5 – Visual concept of noise monitoring in the construction site

Figure 5 above shows the virtual model of the fenced area of the construction site along with neighboring buildings. It is seen that there are 4 sources of noise marked with star-sign, from which the sound waves are distributed spherically. The noise measuring devices are installed on the corners and centers of fences. It is expected that the integrated into the web GIS application algorithm that is based on solving an inverse task expressed by Equations 1-6 along with the interpolation (extrapolation) techniques will give similar picture of the sound distribution in a heatmap manner. Based on known values of SPL, the algorithm should be able to calculate and indicate the locations of the so called "hotspots", which are nothing else than the sound source locations, as well as it should record, show and alarm when the standard limits of SPL are identified anywhere in the map.

4. Conclusions

Review of previous studies revealed that existing noise monitoring systems for construction sites rather measure sound in discrete character and disable estimation of SPL in any other location based on known values, considering the sound as a continuous phenomenon. These systems are expensive and require direct human involvement (i.e., the operator).

Proposed concept is intended to cheapen the cost of noise monitoring system making it almost autonomous. The concept of the system includes noise measuring devices that communicate with data collector remotely using Lora wireless technology, as well as server-side containing database and web GIS application. The GIS application visualizes the data retrieved remotely from the data collector and runs special algorithms. The result is the interactive heatmap of sound distribution over the virtual construction site and surrounding buildings that is updated real-time.

Further studies will be focused on testing and selecting the system components proposed in the concept, as well as assembling and pilot testing of the system. The implemented system in the future enables transparency in the construction noise related issues.

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