Dynamic Monitoring and Displaying Noise Levels in Populated Areas

Review

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Abstract *– Noise is every unwanted sound that surrounds us. Noise has many sources and lately it has become a large-scale problem. Traffic is one of the most important causes of noise. According to its impact on human health, there are regulations that designate maximum permissible noise levels in areas where people work and live. Related work mainly refers to theoretical knowledge applied in numerous scientific papers. There are many states and cities such as Finland, Mexico City, etc., where noise control is recognized as an important issue. Since there are no similar projects in Croatia, we have decided to tackle the problem of noise control. In this paper, we have presented the basic idea of a noise measurement device. Furthermore, we have shown the principle of networking devices in the sensory network. Finally, we have described and exemplified the method for displaying the measured data using the QGIS programming tools. The final idea is to create a system that will collect data and display them in almost real time through a web interface.*

Keywords *– noise, noise control, noise measurement device, sensory network, QGIS*

1. INTRODUCTION

How many times have you heard your favorite song that was too loud? At this point, everything related to the beautiful song was overshadowed with discomfort in our ears. In the following text, we will see what noise is, what its consequences for our health are and how we can register noise. This paper is structured as follows. Chapter 2 describes and defines the concept of *noise*, its impact on human health and standards and regulations that define levels of noise acceptable and recommended for certain activities. Chapter 3 describes prerequisites and hardware preferences for successful and quality noise measurement principles by using ADC based systems. Chapter 4 depicts facts and states related work in the area of noise measurement, monitoring and data displaying/presentation.

Chapter 5 presents a structure of such noise monitoring system for noise measurement, data processing and distribution. Chapter 6 presents a noise mapping technique and its result based on GIS cartography presentation and data rendering. Mapping techniques are shown by the example of noise measurement in one street section of the Čepin town. This data presentation represents a result of the noise monitoring and noise measurement displaying system for fulfilling a goal to structure, organize and build the concept of a noise dynamic monitoring system.

2. WHAT IS NOISE?

Noise is unwanted sound. Rating if the sound is noise is quite subjective. What one believes noise is, someone else does not have to, although both refer to the same sound. Similarly, what noise is for most, an individual does not have to feel the same way. Types of noise are:

- Natural noise – noise from natural sources (thunder, wind noise, the sound of water, etc.),
- Man-made noise - noise created by man (transport, industry, construction, public works, etc.), [1].

Main noise sources in outer spaces are transport, industry, construction and public works, recreation, sport and entertainment. Indoor sources are noise sources connected to the building service equipment, devices for broadcasting music and speech, household machines and noise from next door. Traffic is one of the most important causes of noise. 80% of noise pollution is caused by cars in cities, and on a very busy intersections noise can reach up to 90 decibels, [2].

2.1. THE IMPACT OF NOISE ON HUMAN HEALTH

Studies have shown that noise has an extremely negative impact on people. It has been scientifically proven that noise can cause various psychosomatic disorders, depending on the intensity and the length of exposure to noise. The noise level is measured in decibels (dB), so the impact of noise on human health can be divided into several levels, [3]:

- noise of up to 50 dB interrupts sleep,
- noise of 50-60 dB causes less psychological disturbances,
- noise of 60-90 dB causes severe psychological and neurovegetative disturbances, increases blood pressure, causes rapid breathing, increases the number of red blood cells and disturbs blood sugar regulation,
- noise above 90 dB leads to hearing damage,
- noise above 120 dB leads to acute hearing impairment (TTS, PTS) and causes pain.

2.2. STANDARDS AND REGULATIONS RELATED TO NOISE CONTROL

According to the regulations of the Republic of Croatia referring to the maximum permissible noise levels for the environment in which people work and live (NN145/04), guidelines for describing noise and the conditions of measurement and determination of these quantities are defined in the following standards (Article 2):

- EN ISO1996 -1 -2 -3, Acoustics - Description, measurement and assessment of environmental noise,
- ISO 9612, Acoustics - Guidelines for the measurement and assessment of noise exposure in the workplace,
- EN 60804, sound level meters with integration and routing,

and documents: Noise Protection Act (NN 30/09), Ordinance on the maximum permissible noise levels in the environment in which people work and live (NN 145/04), Regulation on the activities for which it is necessary to determine the measures for noise protection (NN 91/07), Ordinance on conditions relating to location, equipment and staff performing professional noise protection (NN 91/07), and Ordinance on measures for protection from noise sources in the open air (NN 156/08). Depending on the area, the permissible noise levels are divided into maximum allowable noise levels in outdoor and indoor areas, [4].

In Table 1, we can see the maximum allowable noise levels in outdoor areas. Outdoor areas are divided into five zones according to the purpose of the site. The first zone is intended for resting and healing in which criteria are the largest, while the fifth zone is intended for heavy industry. Noise levels for each zone are shown for day and night and they are expressed in the form of average values for the entire period of data collection (LRA_{eq}). We can see that the maximum permissible noise level is 80dB for areas where the industry is located. For the purpose of comparison, normal speech is about 60 dB.

In Table 2, we can see the maximum noise levels in interior spaces. Zones given in Table 2 are identical to those in Table 1. The value of noise is expressed as the mean value of all noise emitted in a given time interval. We can see that the maximum permissible noise levels in indoor living spaces are half the ones in outdoor areas.

Noise is a major problem for human health, so it is necessary to determine its sources and deal with them properly. In the following text, we deal with the methods of measurement and noise displaying. This paper presents a system for monitoring noise in populated areas with the ability to display measured data in almost real time. This approach replaces some older methods that have been used so far.

Table 1. Maximum allowable noise levels in outdoor areas, [4]

Noise zone	The purpose of the site	Maximum permitted noise emmisions LRA_{eq} dB(A) day	night
1	The zone is intended for rest, recovery and treatment	55	40
2	The zone is intended for housing and residence	55	40
3	Mixed-use zone, predominantly residental	55	45
4	Mixed-use zone, mainly business	65	50
5	Zone for commercial purpose (production, storage, service, etc.)	The noise should not exceed 80 dB(A)	

Table 2. Maximum allowable noise levels in indoor living spaces, [4]

Zones as shown in Table 1	1	2	3	4	5
Maximum permitted noise levels LRA_{eq} dB(A) - day	30	35	35	40	40
Maximum permitted noise levels LRA_{eq} dB(A) - night	25	25	25	30	30

3. SIGNAL CONDITIONING AND SYSTEM PREREQUISITES

The signal is information that passes through certain media. All natural phenomena such as noise are analog signals by their form. To be able to process information it is necessary to convert an analog signal to digital. For this purpose, we use the signal conditioning and system prerequisite. A binary number is made up of a series of ones and zeroes. An analog to digital converter transforms an analog value to a binary number and then eventually to a digital number that can be reproduced on the monitor, stored as a number in the database, etc. The number of binary digits - bits that represents a digital number determines the ADC resolution. How closely a digital number approximates the analog value also depends on the ADC resolution. A mathematical relationship shows how the number of bits determines specific theoretical resolution of ADC, (1). For example, a 10 bit ADC has a resolution of one part in 1024, where 2^{10}=1024 .

$$ADC\ resolution = 2^{Number\ of\ ADC\ bits} \quad (1)$$

10-bit ADC with a maximum input of 5 VDC can resolve measurement, (2), into:

$$\frac{5\ VDC}{1024} = 0.0048 \rightarrow VDC = 4.88mV \quad (2)$$

There are several types of ADCs made for all kinds of applications. Types of ADCs are:

- Successive Approximation ADCs,
- Flash ADCs,
- Integrating ADCs - Dual Slope,
- Sigma - Delta ADCs.

They differ in resolution and thus we choose one of them depending on the need. The main criterion when choosing an ADC is its resolution - the number of bits that determines the accuracy of the conversion.

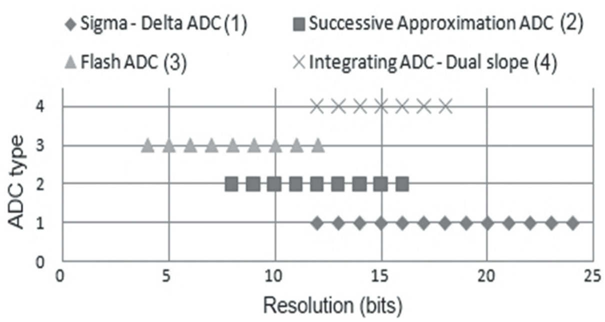

Fig. 1. Applicable resolution ranges with respect to ADC architecture

Depending on the type of ADC shown in Figure 1, we can see resolution ranges for certain ADC architecture, [5].

The Nyquist sampling theorem says that the sampling frequency must be at least twice the highest frequency contained in the signal. This is mathematically expressed by:

$$f_s \geq 2f_c \quad (3)$$

where f_s is the sampling frequency and f_c is the highest frequency contained in the reference signal, [6]. The frequency range of human hearing is generally considered as from 20Hz to 20.000Hz, [7]. According to the Nyquist sampling theorem (3), the sampling frequency must be at least 40,000Hz. With regard to the maximum frequency, it is necessary to collect the same number of samples (40,000 samples). According to equation (1), we can calculate that for this application, it is necessary to take at least a 16-bit ADC (2^{16}=65536 *samples*).

In case you need to increase the number of samples, the Sigma-Delta ADC architecture is most appropriate for this task (it has the largest resolution range, from 12 to 24 bits). For example, we have taken ADC AD7176 from the company Analog Devices that, according Table 3 showing dependence of Output Data Rate and noise, has very low measurement noise and does not significantly affect the accuracy of the conversion. The maximum number of samples per second for a given ADC is 250,000 samples. Because of the small influence of noise and high-speed data conversion, Sigma Delta ADC is the best choice, [8].

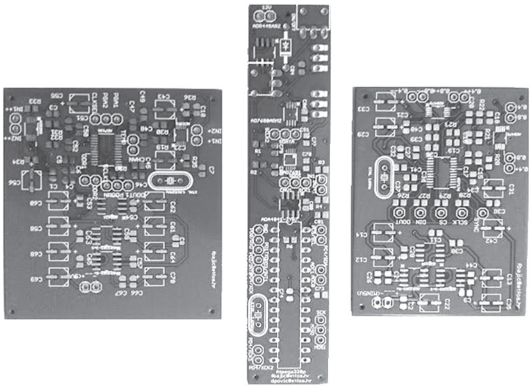

Fig. 2. Printed circuit boards with integrated ADCs of test setup

In certain cases, when great accuracy is required, the sampling frequency can be up to 10 times the maximum frequency of the reference signal.

Table 3. AD7176 Noise vs. Output Data Rate [8]

Output Data Rate (SPS)	Sinc5 + Sinc1 Filter (Default)	
	Noise (μV rms)	Peak-to-Peak Resolution (Bits)
250,000	9.7	17.2
62,500	5.4	18.2
10,000	2.5	19
1,000	0.82	20.8
60	0.46	21.4
50	0.42	21.7
16.7	0.42	21.7
5	0.32	22.2
Output Data Rate (SPS)	**Sinc3 Filter**	
	Noise (μV rms)	**Peak-to-Peak Resolution (Bits)**
250,000	220	12.8
62,500	5.1	18.3
10,000	1.8	19.8
1,000	0.62	21
60	0.32	22
50	0.31	22
16.7	0.29	22.4
5	0.29	22.4

In these situations, Sigma Delta ADC is the right choice again. For the purpose of ADC application suitability testing test setup boards are developed, Figure 2. With these boards, the tests are conducted and the functional principle is confirmed. The Sigma Delta architecture is fully suitable for the purpose of sound signal digital conversion and further processing preparation.

4. RELATED WORK

Since the noise problem has been recognized in the world, there are numerous studies on this topic. Topics covered in the related work mainly refer to the theoretical description of the problem of noise in populated areas. Only a few of them actually deal with data collection and processing. The main reason is that such kind of project is often too expensive, so all achievements are closely guarded. Even if the project is funded by the city or state, a more detailed description of the work is not available. When we talk about the process of data collection and by that we imply the description of the measuring instrument, details are almost inaccessible. The reason is that development of such instruments requires large investments and the main goal is profit. Faced with the lack of reliable sources of knowledge, the only thing that remained was to get better acquainted with the very problem of noise from the available articles and papers.

As to the theoretical approach to the problem of noise, all articles and research papers contain similar theoretical approaches. Depending on the country, different laws apply, so in Croatia standards similar to those in the European Union are applied. In the above paragraphs, we have given a theoretical introduction to the problem of noise. The next step in our research was to devise a measuring instrument. The best way was to study the existing ideas and adapt them to our needs. As technology becomes obsolete very quickly, most of the available work was technologically backward to the present time. As a starting point, we took an article entitled "Design of Networked Low-Cost Wireless Noise Measurement Sensors". In the given article, a team of people from Finland describes the design of the measuring instrument based on the microcontroller atmega328. Measuring instruments have the ability to connect to a host computer that stores the collected data. The main advantage of the present project is the very simplicity of the device. The work does not contain a detailed description of the device, but the principle of collecting, processing and transmitting data was sufficient for our needs, [9].

We have gained some good basic knowledge from the manufacturer of professional equipment, e.g., Bruel & Kjaer. Since the basic problem is sound processing, we have obtained good foundations from technical books created by Analog Devices, a company providing good technical support with a number of their books. The next step in our research was the study of projects dealing with the supervision of noise within a larger city. Nowadays, almost every major city has a project that deals with detection and monitoring of noise levels. Interesting articles mostly relate to large cities where this problem is more pronounced. For example, the article "Monitoring System of Environment Noise and Pattern Recognition" describes the system of measuring instruments in the historic center of Mexico City. Since this place is a tourist attraction, there was a need to control noise pollution, [10]. This is just one example, but if we examine the issue in more detail, we will see that this problem is recognized worldwide. As for the display of measured data, it is sufficient to use the instructions provided on the website of the software package QGIS, [11]. We can conclude that there are numerous projects dealing with the problem of noise control, but to develop your own ideas, it is necessary to conduct your own research.

5. NOISE MONITORING SYSTEM

In the previous paragraph, we have presented other people's ideas and achievements. Based on other people's work, in the following paragraphs we will present our solution to the problem of noise monitoring in urban areas.

Once we have determined how to turn noise into data that can be stored and sent to a remote computer, it is necessary to explain the method of data collection. The traditional way of measuring noise levels demanded setting up of the measuring device on the measuring site. After that, measuring would last several hours. Finally, it was necessary to assemble the device and take it to a new measuring point. We can see that this method of measurement has many drawbacks. First, this type of data collection requires a large number of employees and measuring devices. Otherwise, measurement can take several weeks for larger spaces. Data collected by this measuring are time independent because it can take a significant time from their collection to the playback. The third drawback relates to the need for constant device monitoring. It was necessary to devise a way to gather information about the noise level in a certain area and show them shortly thereafter. The solution to this problem are networking measurement devices. This method solves drawbacks of the traditional way of noise measuring. After defining the critical points, points with increased traffic noise, it is necessary to set up a measuring device that is wired or wirelessly connected to a central computer. This method of data collection does not require a large number of employees. Data are available almost simultaneously and instantaneously, and can be displayed on an interactive map in near real time. Also, measuring devices are much simpler since they do not contain parts for data displaying, filters, numerous ports, large amount of memory, etc. The only task is to record the data and send them to the central computer. In Figure 3, we can see the architecture of the proposed sound level meter (SLM). On the input of SLM, a microphone converts sound into an analog signal. After that, the analog signal is processed to ADC.

Finally, digital signal is forwarded to the digital signal processor (DSP). After processing, data is stored in memory and then sent to the remote computer. Figure 4 shows SLM networking. After collecting, each of the devices sends data to the central computer with one of the available communication methods. The data is then stored in a database. The best choice is to enable both wired and wireless communications.

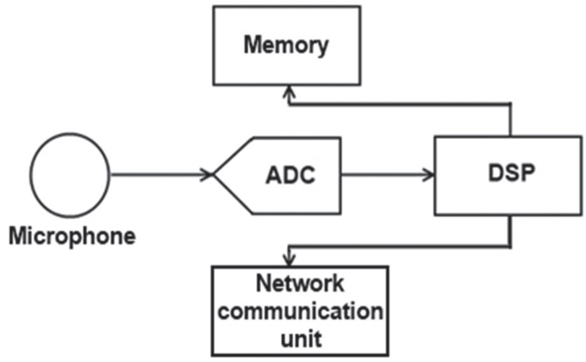

Fig. 3. Sound level meter architecture

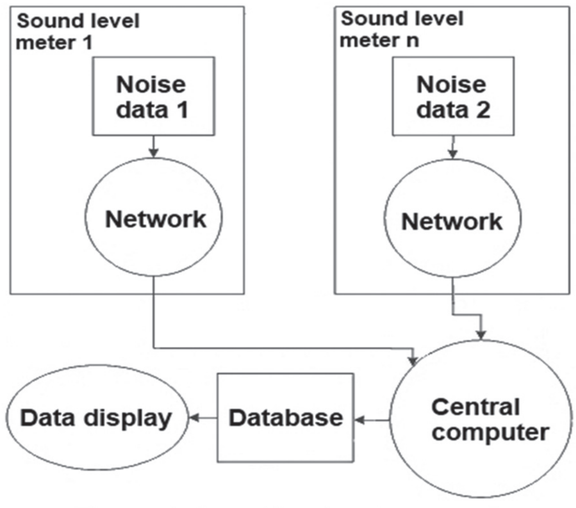

Fig. 4. Sound level meter network

6. NOISE MAPPING

Noise level measurement was performed once every few years for a particular area and then from collected data the map was drawn with the data shown by colors. Mostly the data was in the spectrum from blue to red color where the blue color indicates areas with low levels of noise while the red colored areas indicate excessive noise levels. Since noise maps are produced every few years, the actual situation differs a lot from the one on current maps. By applying our system it is possible to display received data in near real-time. One of the software tools that allows you to add a graphically arranged data layer over the map layer is GIS (the geographic information system). Data collected by means of a measuring device can be displayed in a very simple way in the form of one or more shades of colors.

A geographic information system integrates hardware, software, and data for capturing, managing, analyzing, and displaying of all forms of geographically referenced information. GIS allows us to visualize data in many ways, [12]. Quantum GIS (QGIS) is an open source GIS desktop application. It can be installed on various operating systems, such as Windows, Linux, etc. QGIS is free and has many plugins, [13]. Since it is impossible to collect data at all points of the observed area, there is a need to get approximate values for the missing data. Interpolation is a method for determining the approximate values of data for the areas where we have not collected data. The primary assumption of interpolation is that points close to each other are more alike than those farther away. Spatial interpolation calculates unknown values with known values distributed across the area. It is possible to calculate all missing points with known values but it is recommended to have more measured values that are evenly distributed throughout the entire area. The First Law of Geography states that every measured point is related to the remaining points, but nearest points are more related than points with greater distance. Also, it is possible to control the number of sample points used to estimate missing data (points). If you have more measured values, the process of interpolation will be faster and more precise. It is also possible to set outer borders of interpolation - the farthest points that will be calculated using known points. Interpolation constraints appear when determining the value of points located on the edges of cliffs, rivers, etc. There are three main methods of interpolation:

- Inverse distance weighted,
- Spline,
- Kriging.

The type of interpolation method that will be used depends on many factors. To assume which one of interpolation methods is better than another, the best option is to try different interpolation methods and compare the results, [14].

In the following text, there is an example that shows the process of collection and presentation of data on the map using software tools QGIS.

The first step is to determine the location of the noise measurement. In this case, Čepin was selected as the measuring area. Čepin is located 10 km from the city of Osijek, the Republic of Croatia. Because of its location, state road and regional railway passes through the village, therefore they may represent potential sources of noise. As shown in Table 1, it is necessary to divide the measuring range of measurement zones. Figure 5 shows the measurement area divided into zones (according to Table 1), indicating major and minor roads. Purple color shows the state road D7, which is one of the busiest roads in the country. For this purpose, a few years ago bypass roads around the village were built. Nevertheless, many trucks are still passing through the village. The blue line shows the railway which is directly connected with the city of Osijek. Because of the density of traffic, the first step in our research was to create a noise map which will show noise levels for all roads in the village. The noise map must also contain other noise sources such as industrial plants, etc. In the village, there is an oil factory that is marked on the map as a black area. The rest of the highlighted area is a residential area. The red line around the village represents the area within which it is necessary to measure the noise levels.

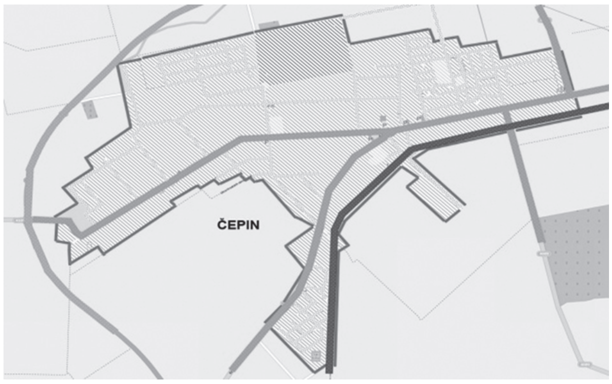

Fig. 5. Measurement area with the indicated zones (as shown in Table 1) and roads

The next step in the process of creating the noise map is a selection of measuring points. Figure 6 shows points in which measurements were conducted. The most detailed measurements were carried out along the state road D7, railroad tracks and nearby industrial plants.

Fig. 6. Measurement points

After collecting the data, the noise levels can be displayed in the form of colored dots (Figure 7). Every shade of color represents an interval of noise in the amount of 3 dB (Figure 8). Blue color shows the lowest measured noise level while the red color shows the maximum measured noise level. Each shade of color gives the number of points located at the specified noise interval (in square brackets []). We can see that more than half of the points are with noise levels greater than 60dB. If we assume that the noise levels up to 60 dB are within the limits of tolerance, it is necessary to omit these points from the displayed noise map (Figure 7). This situation is shown in Figure 9.

Once we get points with increased noise levels (critical point - the point with noise levels greater than 60 dB), it is necessary to make detailed measurements from each of the indicated point.

Detailed measurement was carried out on 4 November 2013 in Čepin, Republic of Croatia. The intersection of two streets was chosen for the measurement site (Figure 10). The measurement was conducted in the period in which the traffic is densest. Figure 11 shows the points at which the measurement is performed. Each point is equally distant from the road. Table 4 contains specific data measured at the indicated points.

$L_{eq}A$ and $L_{eq}C$ represent the mean noise level. The measured data were collected using a professional measuring instrument (2260 Investigator by Brüel & Kjær Company). Figure 12 displays a collection of data stored for each measurement. Depending on the need, you can add or remove measurement parameters. The device allows simultaneous recording over 30 measurement parameters.

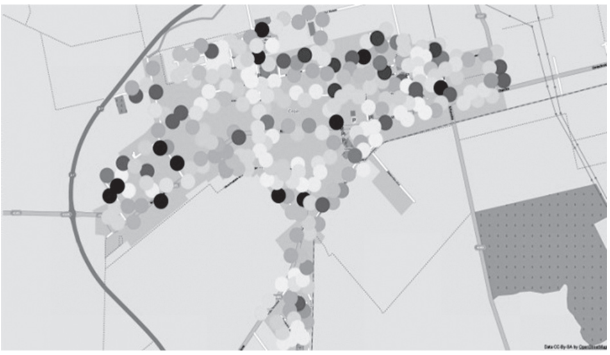

Fig. 7. Displayed noise map in the form of colored dots

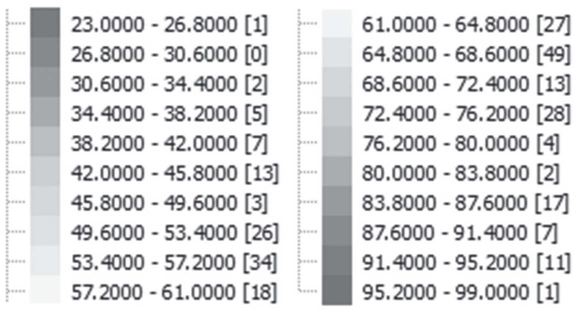

Fig. 8. Intervals of noise in the amount of 3 dB

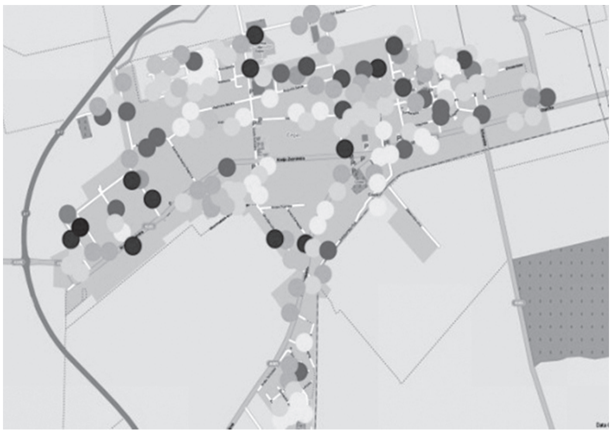

Fig. 9. Displayed noise map for the mentioned situation

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Table 4. Measured data

ID	Date	Time	LeqA	LeqC
1	4 November 2013	11:18:13	96.3	105.7
2	4 November 2013	11:29:54	90.1	105.9
3	4 November 2013	11:38:24	97.5	109.2
4	4 November 2013	11:57:47	92.8	104.9
5	4 November 2013	12:04:41	88.2	107.4
6	4 November 2013	12:12:22	96	107.8
7	4 November 2013	12:19:13	97.6	101.4
8	4 November 2013	12:48:36	95.5	105.2
9	4 November 2013	12:48:36	95.5	105.2
10	4 November 2013	12:34:35	104.1	113.2
11	4 November 2013	12:41:25	84.7	106.6
12	4 November 2013	12:27:04	91.7	105.2
13	4 November 2013	13:12:52	92.2	108.8
14	4 November 2013	12:55:34	87.6	107.2
15	4 November 2013	13:01:26	88.9	105.9
16	4 November 2013	13:06:55	82.5	108.9
21	4 November 2013	11:18:13	96.3	105.7
22	4 November 2013	11:29:54	90.1	105.9
23	4 November 2013	11:38:24	97.5	109.2
24	4 November 2013	11:57:47	92.8	104.9
25	4 November 2013	12:04:41	88.2	107.4
26	4 November 2013	12:12:22	96	107.8
27	4 November 2013	12:19:13	97.6	101.4
28	4 November 2013	12:48:36	95.5	105.2

Finally, the measured data are shown by the colored layer (Figure 13). Red color (darkest area, center) indicates the area with the highest noise levels, while green color (brightest area, the outer part of the data layer) indicates the area with the lowest noise level. Other shades represent a value between the highest and lowest measured value. We can see how the colored data layer truly shows the distribution of noise. From the green border, we can conclude that residential buildings serve as a sound barrier. Near the intersection, we can see where the noise level is the greatest. The reason are cars joining the main street.

Fig. 10. Measurement site

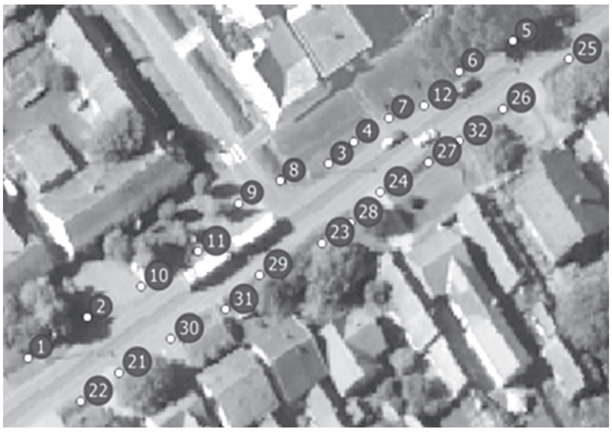

Fig. 10. Measuring points

After joining the main street, they suddenly accelerate emitting thereby significant levels of noise. Along the road, the noise level exceeds 100dB.

Due to a good interpolation method (in this case, a spline), missing points are approximated very accurately. In the process of drawing data on the map, it turned out that not all interpolation methods were suitable for the presented example. In the future, we plan to perform more measurements in which we will test all interpolation methods in order to display the measured data as accurately as possible. Figure 14 shows the mean noise level for each of the measuring points. We can see that all mean values are above 80dB, and in some cases they exceed 100dB. From the present measurements we can conclude that prolonged exposure to this high noise levels can greatly affect human health. Houses located along the road are directly exposed to excessive noise levels. We must consider that the measurement was taken at the time with the densest traffic, but in the future it is necessary to remediate this problem.

Brüel & Kjær Sound Analyzer Type 2260 Enh. Sound Analysis 20 kHz SW BZ7206		
# File: 0002.S3A		
Settings:		
Range	30.2 / 110.2dB	
Sound Incidence Correction	Frontal	
Peaks Over	140.0 dB	
Overall Results:		
Start Date	2013 Nov 04	
Start Time	11:18:13	
Stop Date	2013 Nov 04	
Stop Time	11:23:13	
Elapsed Time	00:05:00	
# Frequency Weighting:	A dB	L dB
Lpk (MaxP.)	96.3	105.7
Leq	68.1	81.1
LEP, d (7:30)	67.8	
LE (SEL)	92.8	

Fig. 12. A set of measurement data recorded using the professional measuring instrument

7. CONCLUSION

Noise has become a problem. Timely noise monitoring is the only way to protect human health. The previous method of collecting and displaying noise data was slow and expensive. It required a large number of both professional equipment and personnel. Measurement results were available only after a few weeks. The dynamic noise monitoring system allows you to view the changes in noise levels in real time. In this way, it is possible to determine critical areas (places with increased noise levels) at the very beginning of their creation. By using a free tool QGIS, it is possible to graphically display the collected data. Because the collected data is stored, it is possible to analyze the problem of noise over a long period of time. Since traffic is one of the main causes of noise, in the future we expect the situation to get worse due to an increasing number of vehicles.

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