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Development of a system for continuous environmental noise monitoring (Smolyan, Bulgaria)

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Abstract. Noise pollution is generally regarded as an exposure of people or wildlife to levels of sound that are annoying, stressful, or damaging to the organism. Humans are exposed to noise constantly, from barely audible levels to potentially painful and damaging levels. Cities and agglomerations are subjected to the environmental noise pollution in a greater extent, so the smaller towns and villages are usually neglected in such monitoring studies. The aim of the present study was to: 1) develop a system for continuous environmental noise monitoring; 2) test and validate the system in the urban area of Smolyan town, Bulgaria; 3) assess the level of noise pollution based on systematic measurements. A simple system for continuous environmental noise monitoring has been developed. The system uses budget noise meters, class 2 (verified to be effective enough), placed in special cells for protection from atmospheric influences. The analogue signal from the sound me-ters is digitized and processed by a microcontroller to obtain the equivalent noise levels. This data is transmitted through an Ethernet controller to ThingSpeak, an IoT application and API for storing and retrieving data using HTTP protocols. Data from the continuous monitoring proved the existence of a significant environmental noise pollution in Smolyan (both in the central part and residential areas), which was almost permanent during twenty-four hours and all year round.

Key words: noise pollution, health risk, traffic, IoT, microcontroller, sound meter.

Introduction

Noise is regarded as unwanted or disturbing sounds into the environment that affects the health and well-being of human, terrestrial and aquatic organisms (Lancet Regional Health-Europe, 2023). Nevertheless, the noise pollution receives far less attention than air or water pollution because it cannot be seen, tasted, or smelled.

Air quality and noise pollution are major concerns for European cities as every year, around 7 million people die prematurely due to diseases related to air pollution all over the world – over 350 thousand of them in the EU area. According to WHO (2011) estimates, at least 1 million healthy life-years (disability-adjusted life-years, DALYs) are lost annually from traffic-related environmental noise alone in western Europe.

Noise is a serious problem for at least one in five EU citizens causing direct and indirect effects on human health. Direct injuries to the auditory system revealed at hearing loss and tinnitus

(Lancet Regional Health-Europe, 2023). Indirect effects are associated with an increased incidence of cardiovascular diseases in addition to causing annoyance, disturbed sleep, and impaired cognitive performance. It is estimated that the burden of disease, estimated as DALYs lost from environmental noise in western European countries alone, is equivalent to 61 ,000 years for ischemic heart disease, 45, 000 years for cognitive impairment in children, 903, 000 years for sleep disturbance, 22 ,000 years for tinnitus, and 654,000 years for annoyance (Lancet Regional Health-Europe, 2023).

European population exposure to noise is increasing compared to other environmental stressors. The control and management of noise in the urban environment is defined in Directive 2002/49/EC "as part of Community policy to achieve a high level of health care and environmental protection". In order to prevent adverse health and environmental effects from the spread and impact of the noise factor, a National System for Monitoring Noise in the Environment has been operating in Bulgaria since 2006 (Regulation No 54, 2011). The Regional Health Inspectorates (RHI) in the country conduct systematic observations on noise load in cities according to the requirements of a special Guidelines methodology (2007), approved by the Bulgarian Ministry of Health. Since January 1, 2006, the Environmental Noise Prevention Act (2005) has been in force in Bulgaria, which lays down the requirements regarding the assessment and management of noise, which appear in the European Union Directive 2002/49/EC.

It was estimated that the environmental noise poses a significant environmental risk and threat to public health in Bulgaria, especially in major cities like Sofia (Dzhambov et al., 2023), Plovdiv (Dzhambov & Dimitrova, 2016), Varna (Chuturkova et al., 2015), etc. Transport noise has the strongest influence on the acoustic environment - its share is 80-85% of the total noise load in these cities.

The continuous increase in the number of motor vehicles in motion and errors in urban planning are the main reasons for the formation of an urbanized environment with an adverse acoustic regime for human health in many Bulgarian cities. For this reason, the law obliges the relevant competent authorities to determine the level of noise pollution in the environment by measuring, assessing and mapping noise levels and developing strategic noise maps, especially for agglomerations with more than 100 000 inhabitants. The so-called acoustic planning aimed at preventing and reducing noise in the environment is being introduced (Environmental Noise Prevention Act, 2005). The Regional health inspectorates are the bodies that annually prepare noise characteristics of populated areas. Through these characteristics, a complex assessment of the noise load of all regional cities in the country, including some larger settlements, is carried out.

The town of Smolyan does not fall under these agglomerations, but the majority of the streets of the city are significantly burdened by vehicle traffic. The noise emitted by them is invariable, with a pronounced seasonal character, related to tourist activity. The noise in the environment caused by local sources on the territory of the municipality is controlled by RHI - Smolyan. The most affected by the traffic noise are found the territories located immediately next to the road routes. The rest of the terrain is affect-ed to varying degrees, depending on the distance to the road route and the presence of barriers along the way of noise propagation (buildings, fences, etc. elements) (Program for Environmental Protection on the territory of Smolyan Municipality, 2022-2028). It should be noted, that the noise measurements are carried out only at certain points, once per year, usually in the period September - October. An annual measurement of the equivalent noise level per point, although averaged over two different days, does not give a clear idea of the noise load at the measurement location. The night-time levels that affect sleep and hence the health and well-being of a person remain absolutely unknown.

Based on the above mentioned, the aim of the present study was to: 1) develop a system for continuous environmental noise monitoring; 2) test and validate the system in the urban area of Smolyan town, Bulgaria; 3) assess the level of noise pollution based on systematic measurements.

Materials and Methods

Development stages of the system

At the beginning of the process of system's construction, an algorithm for actions needed was set as follows:

Step 1. Hardware equipment – sound/noise level meter

Step 2. Programs for the operation of the microcontroller - digitization of the sound level meter signal, equivalent level calculation and uploading the data to the Thingspeak server

Step 3. Development and calibration of the stations

Step 4. Installation of the stations

Step 5. Programming of the Internet page and uploading to the WEB server.

Step 6. Getting data from the DATA server

Step 7. Data processing programs and visualization of results

The block diagram of the system is presented on Fig. 1. Each noise monitoring station consists of a sound level meter with a voltage output, a microcontroller for data processing and an Ethernet controller for transmitting the data to the data server. In addition to the data on the equivalent noise level, data on temperature and air humidity are also transmitted to the server.

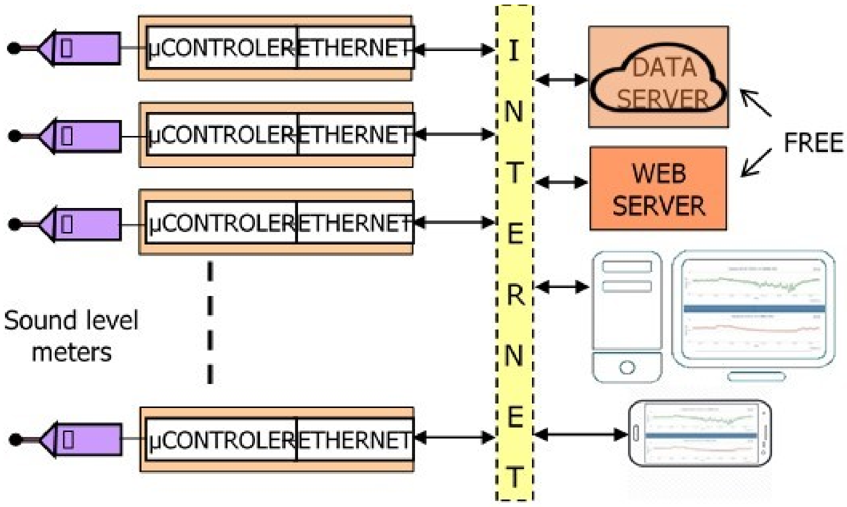

Fig. 1. Block diagram of the system.

Selection of a sound level meter

The class of the sound level meter describes its accuracy as determined by the relevant international standards. Sound level meters are defined by international standards such as IEC 61672-1:2013 or Bulgarian BDS EN 61672-1:2014. These standards de-fine a wide range of accuracy, performance and calibration criteria that instruments must meet in order to be suitable for the purpose of the sound measurement. There are two allowable tolerance levels within the standard and these are known as Class 1 and Class 2. Class 1 sound level meters are called "precision" and those of Class 2 – "general class", mainly because of the different levels of tolerance at different frequencies defined in the standard (Table 1).

Table 1. Performance criteria of sound meters according to the standard IEC 61672-1:2013.

Performance criteria - tolerance limits at reference frequencies	Class 1	Class 2
(IEC61672-1:2013)	+2.5dB, -4.5dB	+5.5dB, - ∞dB
16Hz	+/- 2.5dB	+/- 3.5dB
20Hz	+/- 1.1dB	+/- 1.4dB
1kHz	+2.6dB, -3.6dB	+5.6dB, -∞dB
10kHz	+3.5dB, -17dB	+6.0dB, -∞dB

The biggest differences between the two classes are at the lower and upper limits of the audio frequency range where Class 1 sound level meters have tighter tolerances and are therefore more accurate. At a frequency of 1 kHz, the difference in accuracy between the two classes is 0.3 dB. Considering these differences, the question of the frequency spectrum of street noise naturally arises, so that was postulated as one of the study's tasks.

Road traffic noise has two main sources: the vehicle's engine and drivetrain, and the interaction between the tires and the road. Engine and transmission noise is dominated by low-frequency components with a maximum in the 50 - 100 Hz range (Murphy & King, 2022). Tire noise has a maximum at about 1 kHz, which in the general spectrum smooths out with distance from the source due to the frequency dependence of the propagation attenuation of sound waves (Jonasson, 1999). Another possible source of sound energy in the high frequency part of the spectrum is aerodynamic noise from vehicles at high speeds (Murphy & King, 2022), but this is not typical of urban traffic.

So, regarding this task, a recording with a broadband microphone and amplifier was made and then the noise spectrum of the main street in the town of Smolyan during the day and regular car traffic was analyzed. The spectrum was obtained using the "Frequency Analysis" tool of Audacity program (https://www.audacityteam.org/). The noise energy was found to be concentrated in the 50Hz-4kHz range with a maxi-mum around 230Hz (Fig. 2).

Two types of sound level meters were chosen (Class 1 and Class 2, respectively) and a comparison of their effectiveness for noise level monitoring was made. The devices and their technical properties are presented below (Fig. 3).

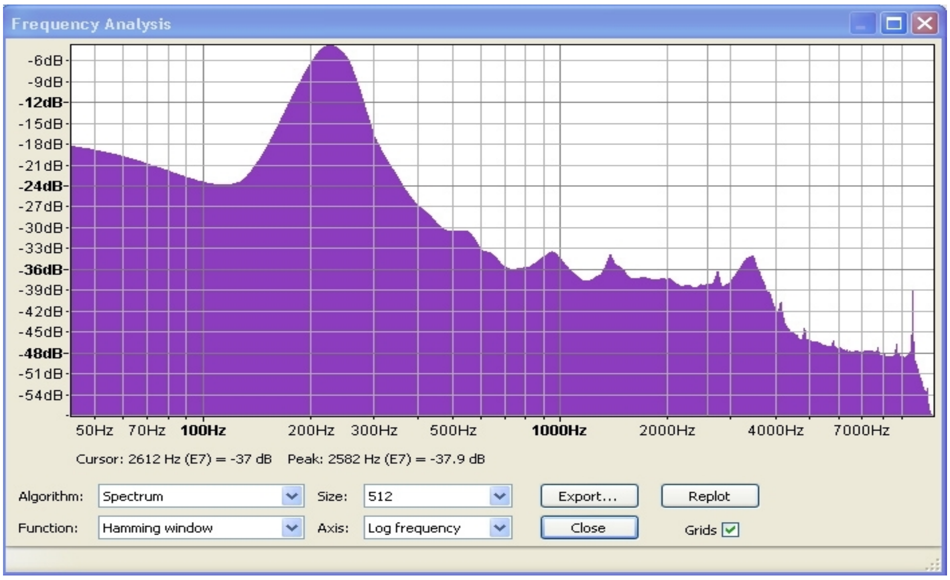

Fig. 2. Spectrum of road traffic noise (recorded on the main street in the town of Smolyan).

B&K2238, Class 1, ± 0.7 dB

GM1357, Class 2, ± 1.5 dB

Fig. 3. Sound level meters' characteristics.

They were compared as follows. The tested and reference sound level meters are located in a horizontal plane, symmetrical to the middle of one side of a parallelepiped-shaped box. The box is made of chipboard with a thickness of 18 mm and inner walls lined with mineral wool. Attached to the center of the opposite base is a small circular full-range speaker (SP), driven by a low-power, wide-band audio power am-plifier (PA). A Sine Wave Generator (FG) from Christian Zeitnitz's Soundcard Oscillo-scope program is applied to the input of the amplifier. A B&K2238, class 1, which passed the metrology test, was used as a reference sound level meter (Fig. 4).

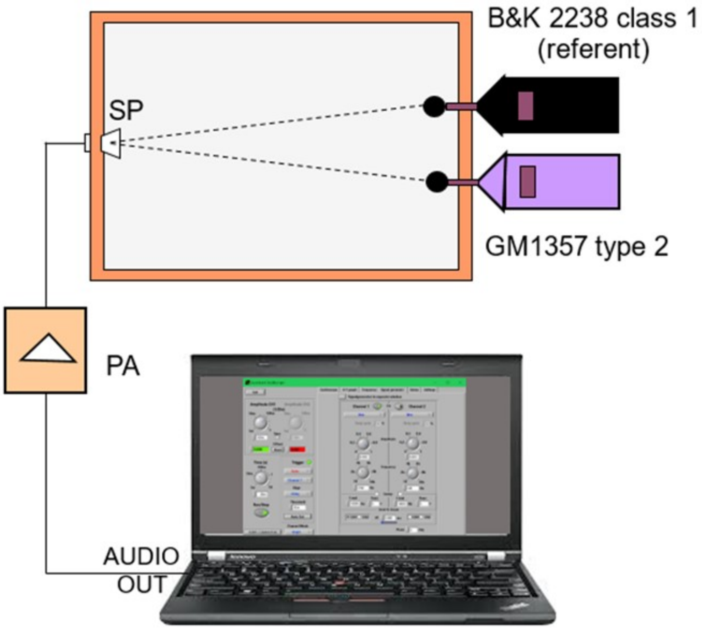

Fig. 4. Experimental design for testing of sound level meters.

The differences in the readings of the tested and reference noise meters (Δ, dB), at different frequencies and different levels of the output signal of the sinusoidal generator (FG), have been calculated and presented on Fig. 5. It can be seen that in the range from 16Hz to 10000Hz the difference in the readings of the tested and reference sound level meters does not exceed ±1.0 dB. Therefore, the tested sound meter GM1357 complies with Class 2. Moreover, in this frequency range where the street noise energy is concentrated, it also meets the requirements for Class 1.

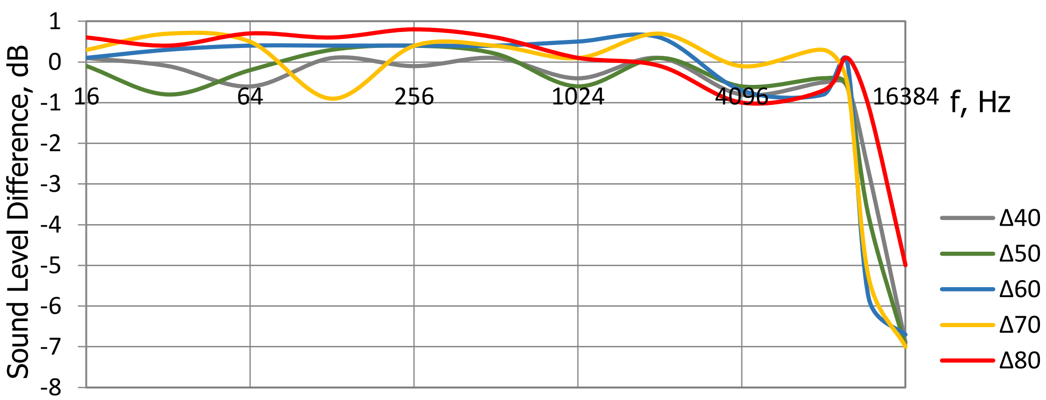

Fig. 5. Sound level meters' comparison.

As a conclusion of the test performed, we proved that in a distributed environmental noise measurement system, we can use the much cheaper Class 2 noise meters instead of the precise but expensive Class 1 with equal success.

So, for use in our system, we chose a Class 2 noise level meter, model GM1357 with analog output. The output analog signal from the sound level meter is propor-tional to the sound level - UDCout[V] = 0.01(LA)[dB] and when the sound level chang-es between 30 and 90 dB it changes from 0.300 to 0.900V. Here (LA)[dB] is the sound level in dB. Since this signal is obtained with the A-weighting of the noise level meter on, the equivalent level calculated by the microcontroller will be A-weighted (LAeq).

Definition of equivalent noise level

Another difference between the two classes is the availability of integrating func-tions on most Class 1 sound level meters to calculate the equivalent level. (The values in the normative documents are given precisely for this level.) However, the digitization of the signal from the analog output of Class 2 sound level meters and the calcula-tion of the equivalent level is not a problem for modern microcontrollers.

An Atmel 328 microcontroller with an Ethernet adapter is used with the Arduino platform to determine the equivalent noise level and send it along with the weather data to the Thingspeak IoT platform.

During a set time interval, the microcontroller digitizes the analogous signal from the noise level meter and at set intervals calculates the equivalent levels according to the formula:

$$LAeq = 10\log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{0.1\,(LA)i}\right] \quad (1)$$

where n is the number of measurements for the given time interval and (LA)i is the value of the measured A-weighted noise level at the i-th measurement.

Data acquisition and processing

The equivalent noise level is calculated according to formula (1) for an intervals of 30 s and 300 s, with individual (LA)i measurements performed every 100 or 1000ms (10Hz or 1 Hz sampling rate).

Data visualization is done on a website, written in a text HTML editor and hosted on a free Internet domain.

The graphics are embedded in the HTML code and are updated in real-time using HTTP requests to the Thingspeak server.

Results and Discussion

Verification and calibration of the experimental setup

To test the operation of the chosen Class 2 sound level meter + microcontroller system, we used the following laboratory setup as shown on Fig. 6. In this case, instead of a generator, the computer plays a 5-minute recording of street noise. The microcontroller (MC) digitizes the analog signal from the sound level meter and at 30 and 300s calculates the equivalent levels L30 and L300 according to formula (1) and transmits them via RS232-USB to the computer.

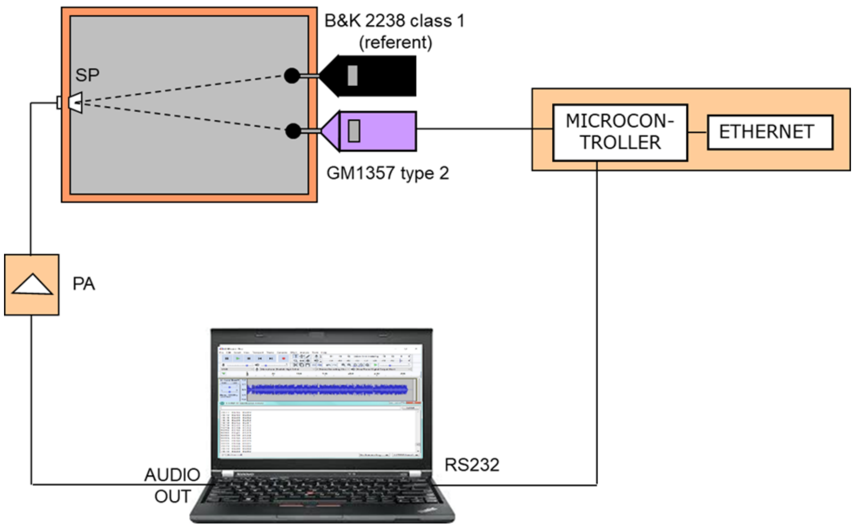

Fig. 6. Laboratory setup for testing the determination of the Equivalent Sound Level.

The difference between the equivalent recording noise levels measured by the Class 2 sound level meter + microcontroller system and the reference sound level meter for 300s at different levels and two different sampling rates 1 and 10 Hz are shown on Fig. 7. It can be seen from the graphs that the differences are within ±0.6dB and that using a lower sampling rate (1Hz) does not result in a significant decrease in accuracy.

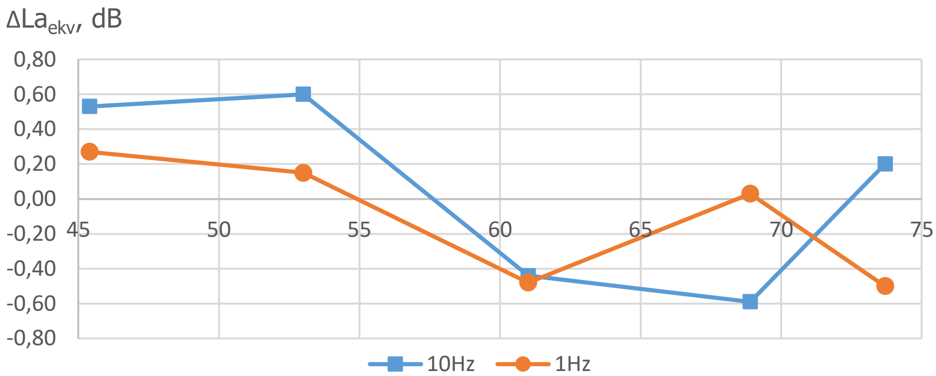

Fig. 7. Calculated values for 300s Equivalent Sound Level Difference (Class2+Program - Class1) at two different sampling rates.

Construction of a noise monitoring station

In order to protect against meteorological influences, the noise meter cell was made in the likeness of the shields of weather cells. They protect the thermometers and hygrometers from precipitation and solar radiation and at the same time ensure unhindered circulation of the surrounding air. Thus, here too, in addition to protecting the sound meter from precipitation and solar radiation, access of the sound waves to it is ensured without major attenuation and distortions. It also allows the installation of other sensors such as temperature, humidity and atmospheric pressure.

The mechanical resistance is ensured by 4 galvanized studs. Through spacer sleeves, they hold 9 polypropylene bowls with slotted bottoms. The sound meter and the temperature-humidity sensor SHT11 are placed in the inner space thus formed (Fig. 8a). The sound level meter is prepared for continuous operation by being redesigned to eliminate automatic power-off when operating on batteries.

A set of 10 noise monitoring stations was prepared and installed in convenient point on the Smolyan's territory (Fig. 8b). The noise meter and the microcontroller are powered by a low-power 6V adapter via the Ethernet cable.

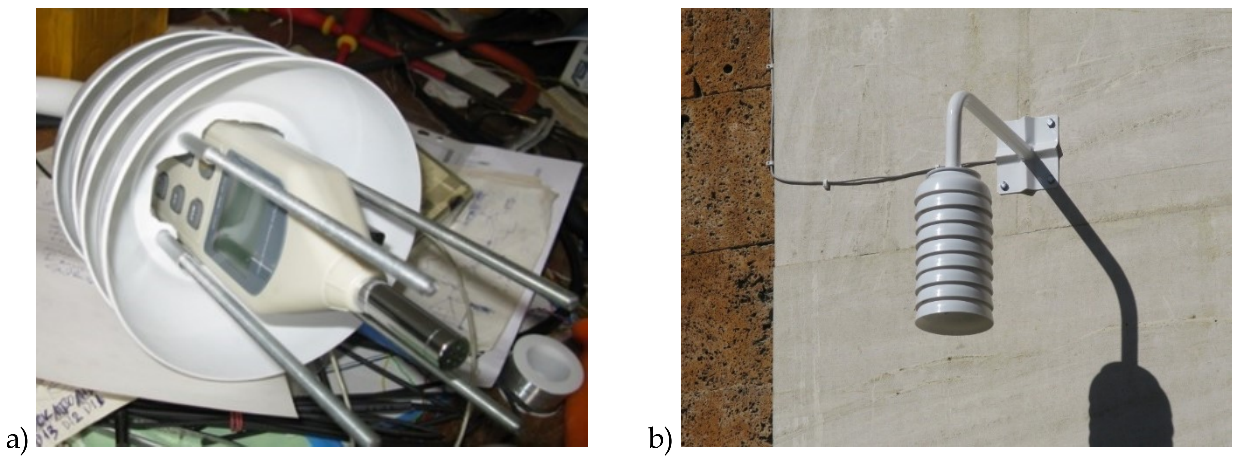

Fig. 8. Noise monitoring station: a) Design of a noise monitoring station; b) General view of the installed noise monitoring station.

System configuration and validation in the urban area of Smolyan town, Bulgaria

The microcontroller receives data from the thermohygrometer via the I2C split, and via the SPI interface controls the Ethernet controller and ensures the transmission of the data to Thingspeak (Fig. 9).

The noise exposure indicators L_{day}, $L_{evening}$ and L_{night} values represent the day, evening and night equivalent noise levels respectively, calculated from the data, downloaded in .csv format from the server of Thingspeak, by using formula (1). L_{min} and L_{max} are respectively the minimum and maximum values of the equivalent noise level, measured by a station.

Data obtained by the system for continuous noise monitoring have been compared to the day, evening and night limit values of the equivalent noise levels (L_{day_n}, $L_{evening\_n}$ and L_{night_n}), according to the regulations in the Republic of Bulgaria (Regulation No 6, 2006), as presented on Table 2.

Fig. 9. Data visualization.

Table 2. Limit values of environmental noise indicators (Regulation No 6, 2006).

Territories and planning zones in the urbanized territories and beyond them	Equivalent noise level dB(A)		
	Day	Evening	Night
Residential zones and areas	55	50	45
Central city areas	60	55	50
Territories subjected to intensive traffic	60	55	50

As a result of the measurements made by the system for continuous noise monitoring, it was found that the average equivalent noise level in RHI Smolyan station is 66-68 dB (above the limit value of 60 dB). Maximum values were in the range 77-78 dB due to the road traffic on Bulgaria Blvd. and the nearby parking lots (Fig. 10).

On the Ustovo station, it was found that the average equivalent noise level is 67-70 dB (above the limit value of 60 dB) and maximum values 76-78 dB (Fig. 11). There are high maximum values of the equivalent noise level generated by road traffic from nearby intersections.

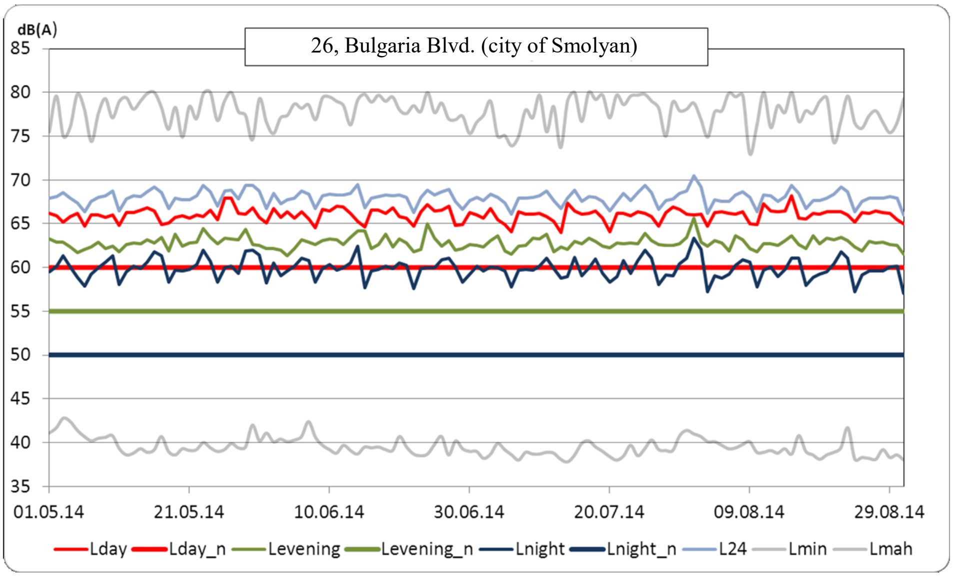

Fig. 10. Data from continuous noise monitoring on Bulgaria Blvd. (central part of Smolyan).

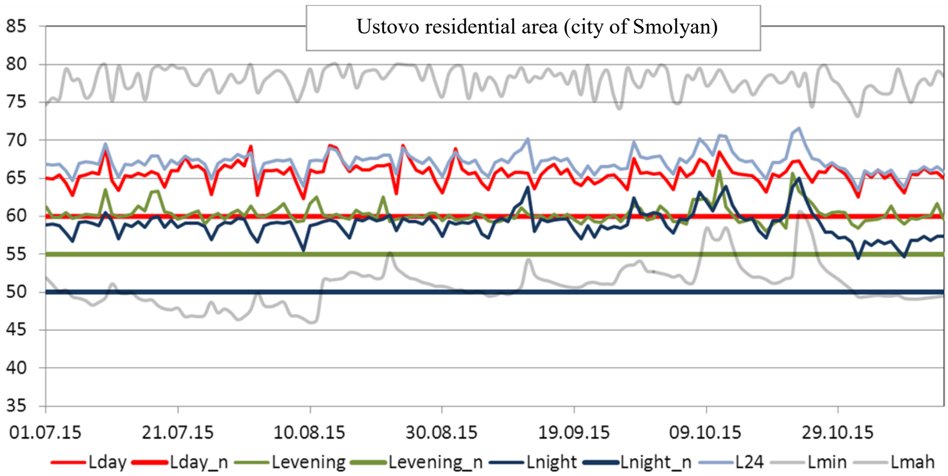

Fig. 11. Data from continuous noise monitoring on Ustovo residential area (Smolyan).

Based on the data obtained, a significant environmental noise pollution was found on the studied territories of the Smolyan town, and it was almost permanent during twenty-four hours and all year round. It was more expressed into the central part where the exceedances of limit values are as follows: 10% of day limit value, 12% of evening limit value, and 15% of night limit value (Table 2, Fig. 10). Station in the Ustovo residential area clearly demonstrated that the exceedances of limit values revealed at 8% above the day norm, 10% above the evening norm, and 15% above the nigh norm.

Many studies have proven that the noise pollution can provoke cardiovascular disorders in pregnant women (Sears et al., 2018), alter the fetal development (Selander et al., 2019), as well as it can lead to disruption of communication and retentive capabilities in children (Tesoriere et al., 2018). Adult population often suffer by annoyance and anxiety (Paiva et al., 2019), mental health crisis (Freiberg et al., 2019), sleep disturbance and insomnia (Eze et al., 2018; Radun et al., 2019). Noise pollution related are found to be also some cardiocerebrovascular diseases (Oh et al., 2019), type 2 diabetes incidence (Dzhambov & Dimitrova, 2016; Thiesse et al., 2018), myocardial infarction incidence (Bräuner et al., 2018; Zock et al., 2018), peptic ulcers (Min & Min, 2018), etc.

Conclusions

A simple system for continuous environmental noise monitoring has been developed. The system uses budget noise meters, Class 2 (verified to be effective enough), placed in special cells for protection from atmospheric influences. The analogue signal from the sound meters is digitized and processed by a microcontroller to obtain the equivalent noise levels. This data is transmitted through an Ethernet controller to ThingSpeak, an IoT application and API for storing and retrieving data using HTTP protocols.

Data from the continuous monitoring proved the existence of a significant environmental noise pollution in Smolyan (both in the central part and residential areas), which was almost permanent during twenty-four hours and all year round. The major source of environmental noise pollution in Smolyan was found to be the road traffic – at stations with intensive road traffic the registered sound levels exceed considerably the established limit values. This problem should be addressed by the Municipality and some possible measures are provided by the EU Committee of the Regions which recommends the adoption of measures mostly at public transport sector, including underground transport systems, walking and cycling alleys, speed limitation, reduction of the traffic flow intensity, etc.

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References

Bräuner, E.V., Jørgensen, J.T., Duun-Henriksen, A.K., Backalarz, C., Laursen, J.E., Pedersen, T.H., Simonsen, M.K., & Andersen, Z. (2018). Long-term wind turbine noise exposure and incidence of myocardial infarction in the Danish nurse cohort. *Environmental International,* 121, 794-802. doi: 10.1016/j.envint.2018.10.011

Chuturkova, R., Stefanova, M., Simeonova, A., Bojilova, V. (2015). Environmental noise pollution from road transport and other sources in Varna, Bulgaria. *International Journal of Research in Engineering and Technology*, 04, 2321-7308.

Directive 2002/49/EO of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise, (2002). OJ L 189, 12-25.

Dzhambov, A., Dimitrova, V., Germanova, N., Burov, A., Brezov, D., Hlebarov, I., Dimitrova, R. (2023). Joint associations and pathways from greenspace, traffic-related air pollu-tion, and noise to poor self-rated general health: A population-based study in Sofia, Bulgaria. *Environmental Research*, 231, 116087. doi: 10.1016/j.envres.2023.116087.

Dzhambov, A., Dimitrova, D. (2016). Exposures to road traffic, noise, and air pollution as risk factors for type 2 diabetes: A feasibility study in Bulgaria. *Noise & Health*, 18, 132-142. doi: 10.4103/1463-1741.181996

Environmental Noise Prevention Act, (2005). State Gazette No. 47/13.09.2005.

Eze, I.C., Foraster, M., Schaffner, E., Vienneau, D., Héritier, H., Pieren, R., Thiesse, L., Rudzik, F., Rothe, T., Pons, M., Bettschart, R., Schindler, C., Cajochen, C., Wunderli, J.M., Brink, M., Röösli, M., & Probst-Hensch, N. (2018). Transportation noise exposure, noise annoyance and respiratory health in adults: A repeated-measures study. *Environmental International*, 121, 741-750. doi: 10.1016/j.envint.2018.10.006

Freiberg, A., Schefter, C., Girbig, M., Murta, V.C., Seidler, A. (2019). Health effects of wind turbines on humans in residential settings: Results of a scoping review. *Environmental Research*, 169, 446-463. doi: 10.1016/j.envres.2018.11.032

Guideline methodology for the determination of the number, situation and spatial distribution of posts for environmental noise monitoring and the intervals for sound level measurements and/or calculations. (2007). Ministry of Health, Sofia, Bulgaria. (in Bulgarian)

Jonasson, H. (1999). *Measurement and Modelling of Noise Emission of Road Vehicles for Use in Prediction Models*. Swedish National Testing and Research Institute, SP Report 1999-35, ISBN 91-7848-794-3, 2001

Lancet Regional Health-Europe. (2023). Noise pollution: more attention is needed. Lancet Reg Health Eur., 24, 100577. doi: 10.1016/j.lanepe.2022.100577.

Min, J.Y., & Min, K.B. (2018). Cumulative exposure to night-time environmental noise and the incidence of peptic ulcer. *Environmental International*, 121(2), 1172-1178. doi: 10.1016/j.envint.2018.10.035

Murphy, E., & King, E.A. (2022). Chapter 7 - Noise Mitigation Approaches. In: Enda Murphy, Eoin A. King, (eds.), Environmental Noise Pollution (Second Edition), Elsevier, pp. 211-255

Oh, M., Shin, K., Kim, K., & Shin, J. (2019). Influence of noise exposure on cardiocerebrovascular disease in Korea. *Science of the Total Environment*, 651, 1867-1876. doi: 10.1016/j.scitotenv.2018.10.081

Paiva, K.M., Cardoso, M.R., & Zannin, P.H.T. (2019). Exposure to road traffic noise: Annoyance, perception and associated factors among Brazil's adult population. *Science of the Total Environment*, 650, 978-986. doi: 10.1016/j.scitotenv.2018.09.041

Program for Environmental Protection on the territory of Smolyan Municipality, 2022-2028. Retrieved from: https://www.smolyan.bg/media/content_files/file/ekologia/03f301af7e5c2e0a9efb3d096cf5d939.pdf (in Bulgarian)

Radun, J., Hongisto, V., & Suokas, M. (2019). Variables associated with wind turbine noise annoyance and sleep disturbance. *Building and Environment*, 150, 339-348. doi: 10.1016/j.buildenv.2018.12.039

Regulation No 54 relating to the functioning of the national system for environmental noise monitoring and on the requirements for monitoring conduction and information submission from industrial sources of environmental noise, (2011). Governmental Newsletter, 2011 (3).

Regulation No 6 on environmental noise indicators defining the degree of discomfort during different parts of the day, the limit values for environmental noise indicators, the assessment methods for environmental noise indicators and harmful effects of noise upon human health, (2006). Governmental Newsletter, 2006 (58).

Sears, C.G., Braun, J.M., Ryan, P.H., Xu, Y., Werner, E.F., Lanphear, B.P., & Wellenius, G.A. (2018). The association of traffic-related air and noise pollution with maternal blood pressure and hypertensive disorders of pregnancy in the HOME study cohort. *Environmental International*, 121, 574-581. doi: 10.1016/j.envint.2018.09.049

Selander, J., Rylander, L., Albin, M., Rosenhall, U., Lewné, M., & Gustavsson, P. (2019). Full-time exposure to occupational noise during pregnancy was associated with reduced birth weight in a nationwide cohort study of Swedish women. *Science of the Total Environment*, 651, 1137-1143. doi: 10.1016/j.scitotenv.2018.09.212

Tesoriere, G., Campisi, T., Canale, A., & Severino, A. (2018). The effects of urban traffic noise on children at kindergarten and primary school: A case study in Enna. *AIP Conference Proceedings,* 2040, Article number 140005. doi: 10.1063/1.5079194

Thiesse, L., Rudzik, F., Spiegel, K., Leproult, R., Pieren, R., Wunderli, J.M., Foraster, M., Héritier, H., Eze, I.C., Meyer, M., Vienneau, D., Brink, M.l., Probst-Hensch, N., Röösli, M., & Cajochen, C. (2018). Adverse impact of nocturnal transportation noise on glucose regulation in healthy young adults: Effect of different noise scenarios. *Environmental International*, 121, 1011-1023. doi: 10.1016/j.envint.2018.05.036

. World Health Organization. (2011). Burden of disease from environmental noise: quantification of healthy life years lost in Europe., World Health Organization-Regional Office for Europe. retrieved from: https://iris.who.int/handle/10665/326424

Zock, J.P., Verheij, R., Helbich, M., Volker, B., Spreeuwenberg, P., Strak, M., Janssen, N.A.H., Dijst, M., & Groenewegen, P. (2018). The impact of social capital, land use, air pollution and noise on individual morbidity in Dutch neighbourhoods. *Environmental International*, 121, 453-460. doi: 10.1016/j.envint.2018.09.008

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