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# Distributed optoelectronic system of environmental monitoring in a real time mode

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## ABSTRACT

The system for monitoring environmental indicators and the state of the environment was developed. It solves the problem of incorrect environmental monitoring using monitoring devices based on Arduino platforms.

**Keywords:** Arduino, sensors, database, back-end, front-end, WebSocket.

## 1. INTRODUCTION

The relevance of the system lies in the use of modern technologies that provide prompt and comprehensive analysis of observations and data visualization of air pollution. During the monitoring carried out air collection, processing, analysis, evaluation and forecasting of air to improve it. As a result, the amount of emissions decreases, removing pollutants, which is important for the natural environment. In order to solve these problems it is necessary to conduct regular monitoring of atmospheric air and to carry out further analysis of the obtained data using modern information technologies<sup>1-5</sup>.

The main idea of the system is the accumulation and processing of environmental information arrays using monitoring devices based on Arduino platforms. The key goal of the system is to create an ecosystem of information database and provide free access to it through web, mobile applications and APIs. One of the advantages of the system is that all information about the state of the environment will have geospatial binding. This will allow the use of numerous methods for processing geospatial information with rendering and analyzing these data<sup>6-8</sup>.

The system aims at solving the problem of incorrect environmental monitoring, when large cities have only 2-5-7 monitoring posts, with the analysis of impurities in the air only 2-4 times a day. It can lead to significant errors in determining the ecological situation in a particular area, and also does not allow to respond promptly to environmental threats<sup>9-11</sup>.

## 2. METHOD

The calculation of the concentration of pollutants in the atmosphere without taking into account the influence of the building is carried out using the method of calculating the concentration in atmospheric air pollutants (OND-86) for point sources and is carried out using the software Mathcad<sup>1,12,13</sup>.

Let's begin the calculation of the calculation of the cost of gas-air mixture:

$$\omega = \frac{4 \times V}{\pi \times D^2}, [mg/m^3], \quad (1)$$

where:  $D$  – diameter of the source of emissions,  $V$  – speed output of gaseous mixture from the tube. Calculation of the coefficients required to determine the maximum concentration of pollutant. The dimensionless coefficient  $f$  is defined as<sup>14</sup>:

$$f = \frac{1000 \times \omega^2 \times D}{H^2 \times \Delta T}, \quad (2)$$

where:  $\Delta T$  – the difference between the temperature of the air-gas mixture and the ambient temperature,  $H$  – height of emission source<sup>2</sup>.

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Another coefficient  $v$  will be equal:

$$v = 0.65 \times \left( \frac{V \cdot \Delta T}{H} \right)^{1/3}, \quad (3)$$

Analyzing the numerical value of the coefficient  $f$  it is necessary to compare it with the value of 100. If the value of the coefficient is less then then we calculate the coefficient  $m$ , which is one of the coefficients that takes into account the conditions for the release of the gas mixture from the source:

$$m = \frac{1}{0.67 + 0.1 \times f^2 + 0.34 \times f^3}, \quad (4)$$

When calculating the second of the coefficients, which takes into account the conditions for the release of the gas-air mixture from the source of emissions  $n$  it is necessary that the conditions  $f \leq 100$  and  $v > 2$  are met. When conditions are fulfilled, the coefficient is calculated according to the formula<sup>1,15</sup>:

$$n = 0.532 \times v^2 - 2.13 \times v + 3.13, \quad (5)$$

After calculating all the parameters, we substitute the values in the general formula and obtain the values of the maximum concentration of the pollutant in the air:

$$C = \frac{A \times M \times F \times m \times n \times \eta}{H^2 (V \times \Delta T)^{1/2}}, [mg/m^3], \quad (6)$$

where:  $A$  – coefficient, which depends on the temperature stratification of the atmosphere (for the territory of the country  $A = 200$ ),  $F$  – dimensionless coefficient taking into account the rate of precipitation of a pollutant in the atmosphere (for gases and fine dispersed aerosols  $F = 1$ ),  $\eta$  – dimensionless coefficient taking into account the influence of terrain (for the whole of Vinnytsia region, where the height differences do not exceed 50 m per 1 km  $\eta = 1$ ),  $M$  – the amount of pollutant leaving the source of contamination in a second<sup>3,16,17</sup>.

To calculate the distance from the source of emissions to the point of maximum concentration of the pollutant, determine the dimensionless coefficient  $d$ , which is calculated by the following formula on condition, that  $0.5 \leq V_m \leq 2$  and  $f < 100$ <sup>6,18,19</sup>:

$$d = 7 \times \sqrt{v} (1 + 0.28 \times f^{1/3}), \quad (7)$$

Calculating the distance to the maximum concentration of contaminating substance:

$$X_{max} = \frac{5-f}{4} \times d \times H, [m]. \quad (8)$$

We construct a schedule for the dependence of pollutant emissions depending on the distance from the source of emissions. To do this, we enter a new variable:

$$R = \frac{X}{X_{max}}, \quad (9)$$

where  $X$  – distance from the source of emissions in meters. After that, we define the parameter  $S(X)$ , which has different formulas depending on the distance from the source of emissions. If the distance on which the concentration is determined is less than the distance  $X_{max}$  then it is determined by the formula<sup>20,21</sup>:

$$S(X) = 3 \times R^4 - 8 \times R^3 + 6 \times R^2 \quad (10)$$

Provided that the distance is greater than  $X_{max}$ , but not more than  $8 \times X_{max}$  formula will look like:

$$S(X) = \frac{1,13}{0,13 \times R^2 + 1} \quad (11)$$

In other cases, when the distance is greater than  $8 \times X_{max}$ , define it as:

$$S(X) = \frac{R}{3,58 \times R^2 - 35,2 \times R + 120}. \quad (12)$$

As an integrated quality of atmospheric air indicator (an indicator that takes into account the presence in the air of all substances, even those in which their concentration does not exceed the TLV), most often the index of atmospheric pollution (IAA) is used<sup>22,23</sup>:

$$I = \sum_i m_i \times \frac{C_i}{TLV_i}, \quad (13)$$

where  $i$  – the amount of pollutants found in the territory air;  $C_i$  – the concentration of  $i$ -th substance,  $\text{mg}/\text{m}^3$ ;  $TLV_i$  – the maximum permissible concentration of the  $i$ -th substance;  $m_i$  – coefficient of environmental hazard of  $i$ -th substance.

The value of the ecological hazard ratio is determined in the Table 1<sup>7</sup>.

Table1. Danger classes of normalized substances.

Class of danger	The degree of danger	TLV size, $\text{mg}/\text{m}^3$	Environmental hazard ratio
I	Extremely dangerous	<0.1	1.7
II	Highly dangerous	0.1–1.0	1.3
III	Moderately dangerous	1.0–10.0	1.0
IV	Lowdangerous	>10.0	0.9

### 3. RESULTS

Calculation of nitrogen dioxide ( $\text{NO}_2$ ) distribution. The maximum permissible concentration of nitrogen dioxide in the air is  $0.085 \text{ mg}/\text{m}^3$ . Let the enterprise have one source of emissions, a height of 23 m and a diameter of 1.5 m. The ambient temperature is equal  $20^\circ\text{C}$ . Emissions of contaminants form  $0.0785 \text{ g}/\text{s}$ . Output speed of the contaminating substance from the pipe  $0.3 \text{ m}/\text{s}$ <sup>1</sup>.

After calculating all the coefficients and parameters, we have the following results.

$$\begin{aligned} \omega &= 0.17 & f &= 1.022 \cdot 10^{-3} & \vartheta &= 0.659 & m &= 1.414 \\ n &= 1.957 & C &= 0.017 & d &= 5.844 & X &= 167.982 \end{aligned}$$

Determining the coefficients of environmental hazard for the specified substances. The results recorded in the Table 2.

Table 2. Determination of the coefficients of environmental hazard of substances.

Pollutant	TLV, $\text{mg}/\text{m}^3$	Environmental hazard ratio
Dust	1	1.3
Carbon monoxide	250	0.9
Nitrogen dioxide	0.085	1.7
Nitrogen oxide	0.085	1.7

As you can see, peak concentrations come at a distance of 168 meters. This means that the concentration from the source of emissions will increase to the maximum value at a specified distance. After that, it will gradually decrease to zero. The graph of the concentration of nitrogen dioxide in the air from the distance to the source of emissions is shown at the Figure 1.

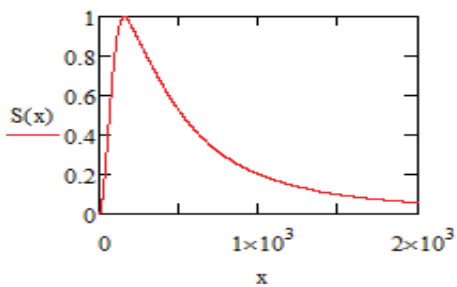


Figure 1. Graph of nitrogen dioxide concentration in air from the distance from the source of emissions.

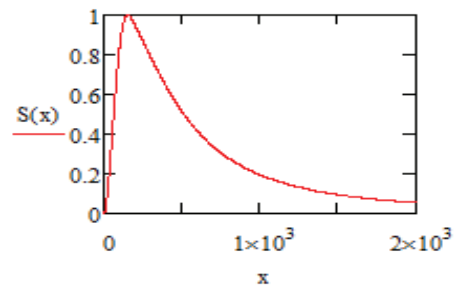


Figure 2. Graph of nitrogen oxide concentration in air, depending on the distance to the source of emissions.

Calculation of the propagation of nitrogen oxide ( $\text{NO}$ ). The maximum permissible concentration of nitrogen oxide in the air is  $0.085 \text{ mg}/\text{m}^3$ <sup>6</sup>. Let the enterprise have one source of emissions, a height of 19.4 m and a diameter of 1.1 m. The ambient temperature  $20^\circ\text{C}$ . Emissions of contaminants form  $0.0815 \text{ g}/\text{s}$ . Speed of contaminants release from the pipe  $0.5 \text{ m}/\text{s}$ <sup>7</sup>.

After calculating all the coefficients and parameters, we have the following results.

$$\begin{aligned} \omega &= 0.526 & f &= 9.62 \cdot 10^{-3} & \vartheta &= 0.841 & m &= 1.33 \\ n &= 1.715 & C &= 0.015 & d &= 6.803 & X &= 164.644 \end{aligned}$$

As we see, peak concentrations come at a distance of 165 meters. This means that its source concentration will increase to a maximum value at a specified distance. After that, it will gradually decrease to zero. The graph of nitrogen oxide concentration in air from the distance to the source of emissions is shown at the Figure 2<sup>1</sup>.

Calculation of the carbon monoxide distribution (CO). The maximum permissible concentration of carbon monoxide in the air is 250 mg/m<sup>3</sup>. Let the enterprise have a source of emissions 29.4 meters high and 1.9 meters in diameter. The ambient temperature 20°C. Emissions of contaminants form 0.0959 g/s. Speed of contaminants release from the pipe 0.8 m/s.

After calculating all the coefficients and parameters, we have the following results.

$$\begin{aligned} \omega &= 0.282 & f &= 1.675 \cdot 10^{-3} & \vartheta &= 0.921 & m &= 1.4 \\ n &= 1.62 & C &= 5.502 \cdot 10^{-3} & d &= 6.941 & X &= 254.985 \end{aligned}$$

As we see, peak concentrations come at a distance of 255 meters. This means that its source concentration will increase to a maximum value at a specified distance. After that, it will gradually decrease to zero. The graph of the concentration of carbon monoxide in the air from the distance to the source of emissions is shown at the Figure 3<sup>2</sup>.

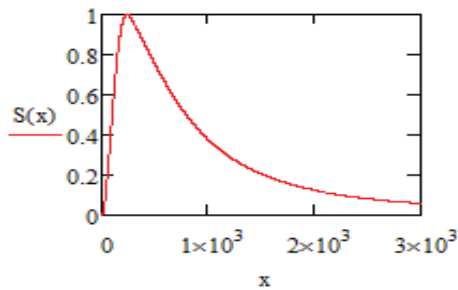


Figure 3. Graph of concentration of carbon oxide in air, depending on the distance to the source of emissions.

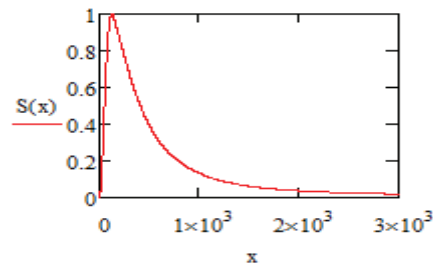


Figure 4. Graph of dust concentration in air, depending on the distance to the source of emissions.

Calculation of dust propagation. The maximum permissible concentration of dust in the air is 1 mg/m<sup>3</sup>. Let the enterprise have a source of emissions 15 meters high and 1 meter in diameter. The ambient temperature 20°C. Emissions of contaminants form 0.0794 g/s. Speed of contaminants release from the pipe 0.6 m/s.

After calculating all the coefficients and parameters, we have the following results.

$$\begin{aligned} \omega &= 0.764 & f &= 0.047 & \vartheta &= 0.848 & m &= 1.228 \\ n &= 1.706 & C &= 0.026 & d &= 7.096 & X &= 131.806 \end{aligned}$$

As we see, peak concentrations come at a distance of 132 meters. This means that the concentration from the source of emissions will increase to the maximum value at a specified distance. After that, it will gradually decrease to zero. The graph of the concentration of dust in the air from the distance to the source of emissions is shown at the Figure 4<sup>3</sup>.

To implement the system were set tasks related to collecting data and sending to the server, as well as visualization and processing using WEB-technologies. The monitoring system is based on the Arduino platform and consists of two modules. They are responsible for the programming / configuration, battery and charging system of the Li-Ion battery, systems for collecting information and pre-processing them, then send to the server.

The schematic diagram of the sensor module is shown at the Figure 5. It consists of several sensors from which information is sent to the microcontroller and is further processed and sent via the I<sup>2</sup>C interface to the main module. It constructs the transmission of data from the sensor module to the main module.

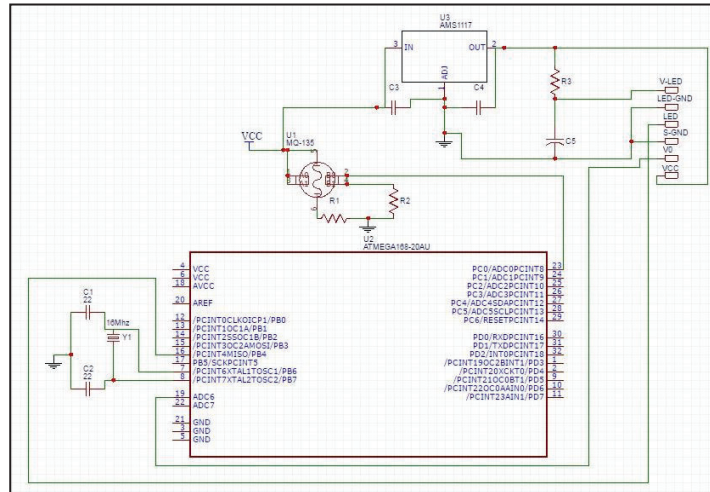


Figure 5. The schematic diagram of the sensor module.

As a quality air sensor, the multifunctional MQ135 was chosen to determine the concentration of NH<sub>3</sub>, NO, alcohol vapors, gasoline, smoke, CO<sub>2</sub>, etc. The sensor generates information in analog form. To analyze the dust content in the air, an infrared sensor such as GP2Y1010AU0F is used. It uses an optical sensing system. The device is built on measuring reflected light with dust or smoke in the air <sup>3</sup>.

#### 4. PRACTICAL REALIZATION

The high-performance, low-power Atmega168 RISC microcontroller is used to process data collection from a distributed sensor system, pre-processing and communication with the server<sup>9</sup>.

To implement the system were set tasks related to the reception of data by the server, their visualization and processing using WEB-technologies. Nowadays there are quite a lot of systems with the implementation of similar tasks, all of them work on a rather similar principle. WEB-site of the system receives data, performs processing and visualization in the most convenient way. The user interface is implemented on the basis of adaptive technologies that allows you to work in the system from both a computer and a mobile device. The block diagram of the system is shown at the Figure 6 <sup>10</sup>.

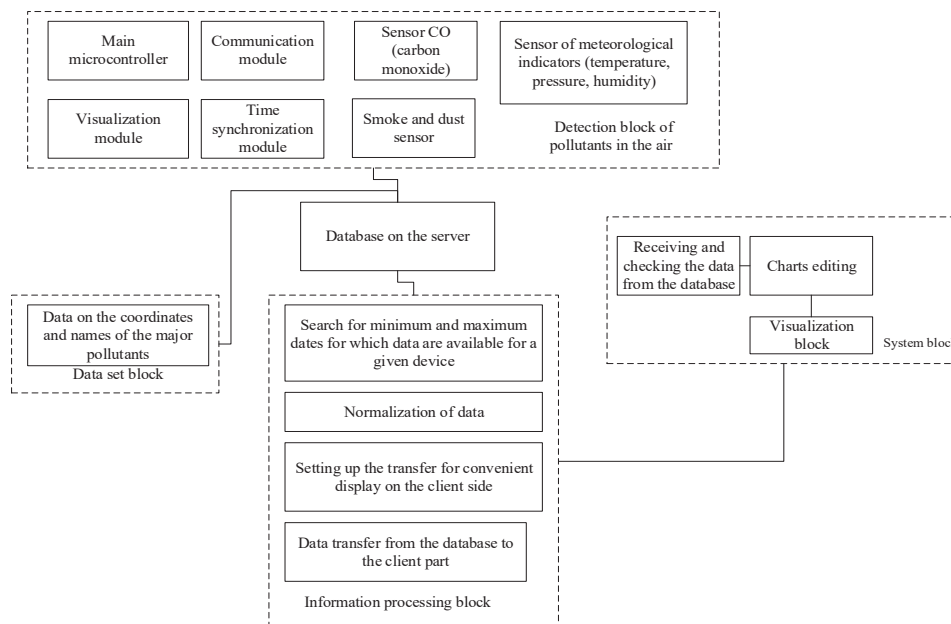


Figure 6. The block diagram of the environmental monitoring system.

Server communication with sensors is done using POST requests. The assembly and preprocessing module adds the received data to the collection of the sensor when receiving data from the sensor in the format Json. This collection is stored in the database and in parallel with it sends the received data to all users in the system. After that, the client module processes and displays them in a user-friendly manner<sup>11-13</sup>.

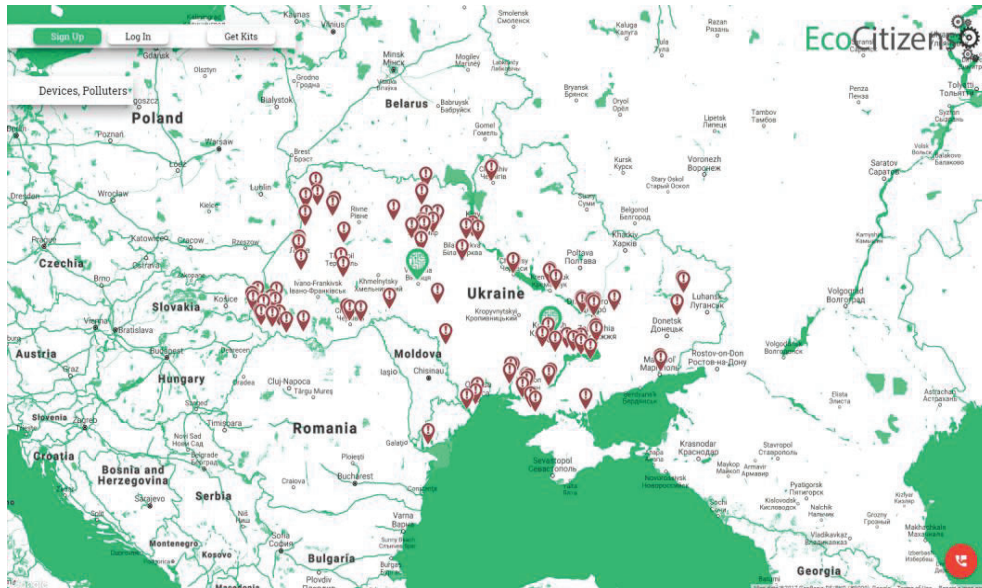


Figure 7. Screenshot of the system main page.

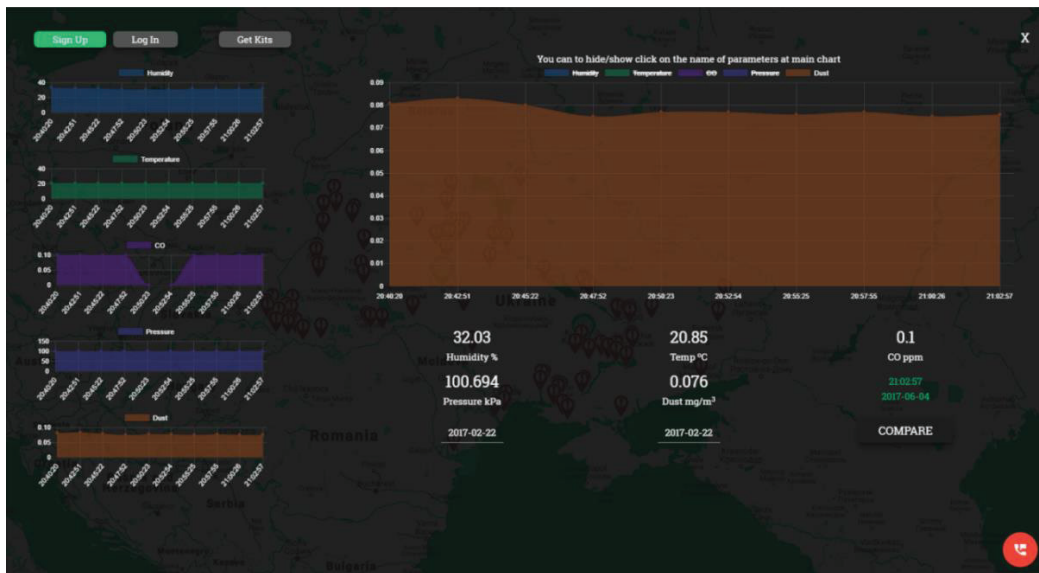


Figure 8. Display information of the selected device.

The feature of the client module system is the use of geolocation based on Google technologies. Due to communication with the module for collecting and pre-processing information based on WebSocket technology, when the page downloading, information about the coordinates of sensors in the format Json is obtained. It is played on a map in the form of beacons. Functional provides a series of filters that allow the user to select information by the necessary features. The reproducible data is formed on the basis of previously collected information from the database, and live in real time with the sensors selected by user. The user selects a specific sensor for monitoring, this activates the server dialogue and information gathering module based on WebSocket technology. The assembly and pre-processing module responds to the request and sends a collection of data to the server. It will be enough to display charts with detailed information on

the measurements made by the relevant devices. After receiving this collection, the client module puts these data in charts and shows in real time the displays of our devices in a separate field. The main functionality of the site is the display of specific indications taken in real time. When you select a device on a map, a window with graphs and real displays will appear at the touch of a left mouse button.

The collected data is recorded in the database, which provides an opportunity to analyze them in a time retrospective for the specified period. After selecting and clicking the corresponding button, a WebSocket technology request is sent again. The module for collecting and preprocessing information sends to the listener of the client module a more massive collection of data. It is processed and applied to the charts in such a way that it does not interfere with the real-time data to be displayed separately. This uses another listener that does not conflict with the previous one.

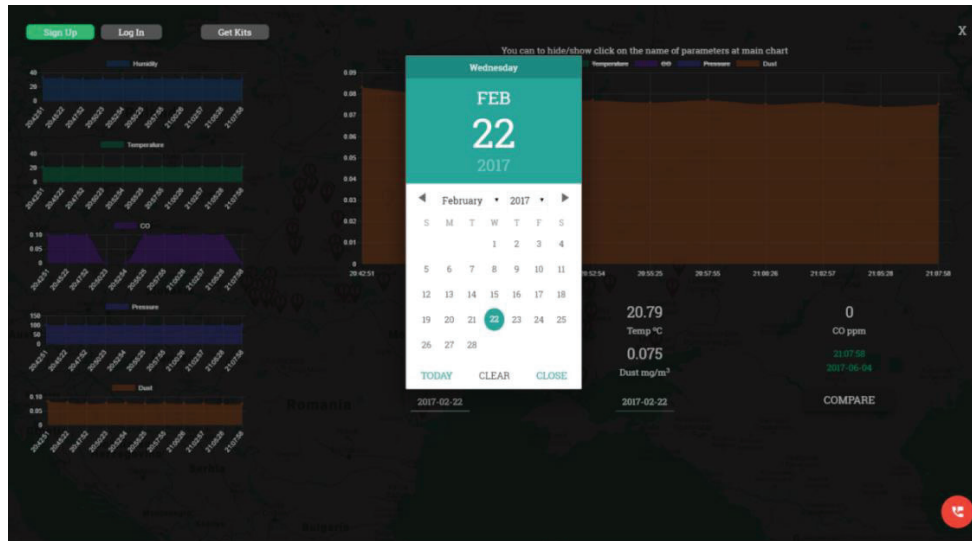


Figure 9. Filter of historical information of the selected device readings.

## 5. CONCLUSIONS

The developed network of monitoring with the central database and its free access to it allows to organically combine this system with technologies for the development of "Smart City". It is possible to create numerous operational alerts on the state of the environment on the basis of the system

The results of long-term observations have a scientific value. On the basis of these data, it is possible to clarify the main patterns of the formation and spread of pollutants within specific settlements. According to the results of the data analysis obtained by the system, it is possible to simulate the influence and spread of pollution from point and spatial sources in the area. The resulting model calculations can apply on natural maps, such as vegetation maps or maps on residential areas in the region. As a result, it enables to quickly evaluate the immediate and future consequences of such extreme situations as emissions of gases and other harmful substances, as well as the impact of permanent point and plane pollutants.

## REFERENCES

- [1] Sun, W.-Y. and Chang C.-Z., "Diffusion model for a convective layer. Part 2: Plume released from a continuous point source," *J. Climate Appl. Meteorol.* 10, 1454-1463, (1986).
- [2] Pasquill, F., [Atmospheric dispersion parameters in gaussian plume modeling – Part II. Possible Requirements for Change in the Turner Workbook Values], U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, (1976).
- [3] Turner, D. B., [Workbook of atmospheric dispersion estimates: an introduction to dispersion modeling], CRC Press (1994).



- [4] Guz, Ł., "Application of semiconductor gas sensors array for continuous monitoring of sewage treatment process regularity," *Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska – IAPGOS* 4, 85-91, (2015).
- [5] Borecki, M., Duk, M., Kociubiński, A. and Korwin-Pawlowski, M. L., "Multiparametric methane sensor for environmental monitoring", *Proc. SPIE* 10175, 101750M, (2016), doi: 10.1117/12.2261498.
- [6] Seinfeld, J. H., [Atmospheric chemistry and physics: from air pollution to climate change. Chapter 18], Wiley, (2006).
- [7] Steven, H., [Handbook on Atmospheric Diffusion], U.S. Department of Energy Report, (1982).
- [8] Shi Yining and Mohite Sagar, [Jumpstarting the Arduino 101 - Interacting With a Computer That Learns], Maker Media, (2017).
- [9] Kurniawan, A., [Digispark USB Development Workshop], PE Press, (2015).
- [10] Wijnen Bas, Anzalone, G. C. and Pearce, J. M., "Open-source mobile water quality testing platform," *Journal of Water, Sanitation and Hygiene for Development* 3, 532–537, (2014).
- [11] Makfarland, D., [New Big Book CSS], Pyter, Sankt Petersburg, (2016).
- [12] Flanagan, D., [JavaScript. Detailed Guide], Symbvol Plus, Sankt Petersburg, (2012).
- [13] Geary, D., [Core HTML5 Canvas: Graphics, Animation, and Game Development], Prentice Hall, (2012).
- [14] Krak, Y. V., Barmak, A. V., Bagriy, R. A. and Stelya, I. O., "Text entry system for alternative speech communications," *Journal of Automation and Information Sciences* 1, 65-75, (2017).
- [15] Kryvonos, Iu. G., Krak, Iu. V., Barmak, O. V. and Bagriy, R. O., "Predictive text typing system for the Ukrainian language," *Cybernetics and systems analysis* 4, 495-502, (2017).
- [16] Koprowski, R., Zieleznik, W., Wrobel, Z., et al., "Assessment of significance of features acquired from thyroid ultrasonograms in Hashimoto's disease," *Biomedical Engineering Online* 11, 48, (2012).
- [17] Wojcik, W., Golec, T., Kotyra, A., et al., "Concept of application of signals from fiber-optic system for flame monitoring to control separate pulverized coal burner," *Proc. SPIE* 5484, 427-431, (2004).
- [18] Wojcik, W., Kotyra, A., Golec, T., et al., "Vision based monitoring of coal flames," *Przegląd Elektrotechniczny* 3, 241-243, (2008).
- [19] Smolarz, A., Wojcik, W., Ballester, J., et al., "Fuzzy controller for a lean premixed burner," *Przegląd Elektrotechniczny* 7, 287-289, (2010).
- [20] Kaczmarek, C., Wojcik, W., et al., "Measurement of pressure sensitivity of modal birefringence of birefringent optical fibers using a Sagnac interferometer," *Optica Applicata* 1, 5-14, (2015).
- [21] Wojcik, W., "Application of fibre-optic flame monitoring systems to diagnostics of combustion process in power boilers," *Bulletin of the Polish Academy Of Sciences - Technical Sciences* 2, 177-195, (2008).
- [22] Wojcik, W., Kisala, P., "The method for the recovery of the apodization function of the fiber Bragg gratings on the basis of its spectra," *Przegląd Elektrotechniczny* 10, 127-130, (2010).
- [23] Wojcik, J., Wojcik, W., Janoszczyk, B., et al., "Optical fibre system for flame monitoring in energetic boilers," *Proc. SPIE* 3189, 74-82, (1997).