Software for Modelling the Air Pollution by Vehicles

Vasyl Tymchyshyn, Natalia Porplytsya, Andriy Melnyk, Bohdan Tymchyshyn

Department of Computer Science, Ternopil National Economic University, UKRAINE, Ternopil, 8 Chekhova str.,
email: tymchyshynn@gmail.com, ocheretnyuk.n@gmail.com, melnyk.andriy@gmail.com, tymchyshyn.bohdan@gmail.com

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Abstract: **In this work the issues of the ecological safety of motor transport, the impact of motor vehicles on the environment are highlighted. Directions and measures concerning the raised ecological safety of motor transport are determined.**

Keywords: **motor vehicles, emissions from motor vehicles, automobile fuel, software complex.**

I. Introduction

One of the most powerful sources of urban air pollution is road transport, the increase in the number of which has led to a sharp deterioration of sanitary conditions in large cities. Motor transport pollutes the air with toxic components exhaust gases, fuel pairs, tire wear products, brake linings, creates noise and vibration. Emissions from motor vehicles negatively affect the physiological state of humans and animals, pollute water, destroy soils, vegetation, building materials, architectural and sculptural monuments, cause corrosion of metals, etc [1].

The problem of a comprehensive solution of the ecological problems in the city consists in the absence of a unified monitoring system, one of the fundamental principles of which is the interconnected network of observation, control, collection and processing information for the analysis, assessment and forecasting the state of environmental pollution. Therefore, the task of realization of the software complex for automation of the process of monitoring and visualization atmosphere pollution by harmful emissions of vehicles (in particular, nitrogen dioxide) in time is actual.

II. Methods For Measuring The Concentrations Of Harmful Substances In The Near-Ground Layer Of The Atmosphere

There are two main methods of measuring the harmful substances in the air: chemical analysis and microbiological analysis.

The chemical analysis of air provides information on the qualitative and quantitative composition on the basis of which it is possible to predict the degree pollution and plan the implementation of measures to control air quality. Detects indicators such as dust, sulfur dioxide, nitrogen dioxide, carbon monoxide, phenol, ammonia, hydrogen chloride, formaldehyde, benzene, toluene, etc. This technique allows to determine the presence in the air of volatile organic compounds with a boiling point of 40 to 250 ° C, affecting human health (phenols, phthalates, organic acids, aromatic compounds, ethers, morphine and other compounds - up to 250).

Microbiological analysis air allows us to establish the presence of biological aerosols (bacteria and fungi). It is necessary to conduct detection pathogenic microorganisms according to such indicators as: total number of microorganisms, gold staphylococci, mold and yeast. Gas analysis of air is carried out using a device called a gas analyzer. Gas analyzer is a measuring device for determining the qualitative and quantitative composition of gas mixtures.

Depending on the pressure in the reaction chamber, gas analyzers of atmospheric and low pressure are distinguished. Gas analyzers with built-in NO_2 / NO converters produce analytical signals for NO, NOx and NO_2 simultaneously or sequentially. Table 1 gives a comparative characteristics NO_2 measuring devices.

TABLE 1. Comparative characteristics NO_2 measuring devices

Name	DGS-NO_2 968-037	Ug-2	Polar
Price(UAH)	2100	4000	6000
Dimensions	44.5 x 20.8 x 8.9 mm	110 x 105x 200 mm	148×164×80 mm
Measurement error	15%	25%	20%

Nitrogen dioxide is a toxic substance, which is why the important task is to control the release this compound.

Many devices have been developed to measure nitrogen dioxide, but one of the most effective uses is the use of the DGS-NO_2 968-037 sensor as it many advantages, such as low price, high resolution etc.

Fig. 1 shows the general view of the sensor DGS-NO_2 968-037.

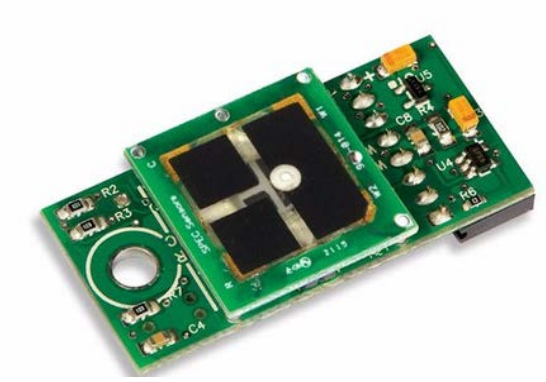

Fig.1. General view of the sensor DGS-NO_2 968-037

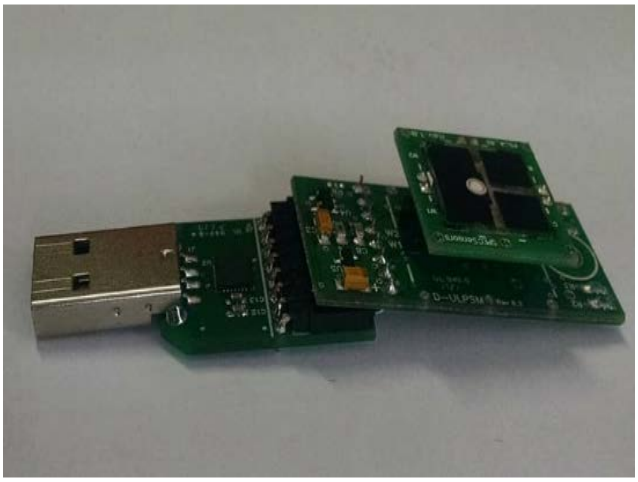

Fig.2. Connected DGS-NO2 968-037 to USB-Bridge UART

Note, that the software and hardware complex for modeling the pollution of the atmosphere by motor transport, designed within this work, it contains a sensor DGS-NO_2 968-037 for the collection experimental data.

III. Features of Collecting the Experimental Data

To collect experimental data on the pollution of air by harmful emissions of vehicles, the study was conducted at the crossroads of the streets Za Rudkoyu str. and Chekhova srt., because precisely at this point one of the most intense automobile streams of the "New World" micro district in Ternopil.

Experiment date: 27.10.17, time from 14.00 to 15.00, air temperature 11^{0}C, air humidity 74%. For effective measurement nitrogen dioxide concentration, the sensor should be located at the point of the road as close as possible to the asphalt surface, because in this point the concentration of NO_2 is maximal.

Table 2 shows the averaged NO_2 concentrations obtained over an hour by measuring the concentration of the DGS-NO_2 968-037 sensor. The format of the output is: Sensor number [XXXXXXXXXXXX], PPB (Part per billion) [0: 999999], Temperature (^{0}C) [-99:99], RH [0:99], RawSensor [ADCCount], TempDigital, RHDigital, Day [0:99], Hour [0:23], Minute [0:59], Second [0:59].

TABLE 2. AVERAGED NO_2 CONCENTRATIONS

Time (min)	NO_2, ppb	NO_2, ppm	NO_2 mg/m^3
10	20,9	0,0209	0,0423
20	11,15	0,01115	0,02259
30	8,683333	0,008683333	0,01759
40	14,76667	0,014766667	0,02992
50	9,5	0,0095	0,0192
60	3	0,003	0,00608

Note, that the measurements were made at a frequency of 10 seconds, so Figure 3 shows the averaging values of the concentration of nitrogen dioxide in 10 minutes.

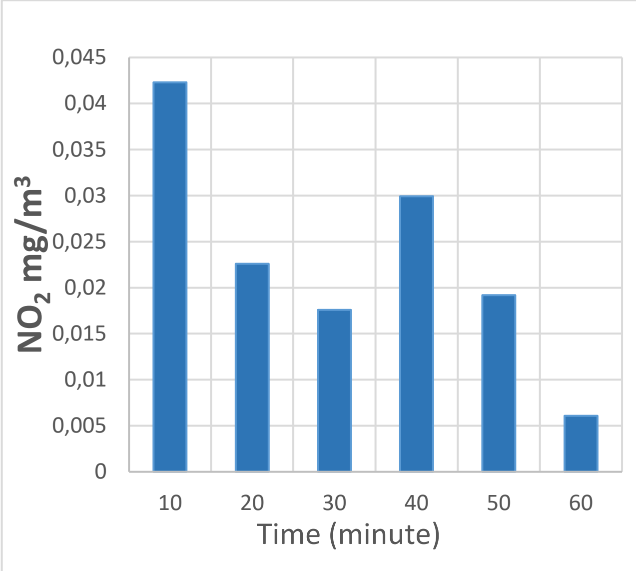

Fig.3. The fragment of the measured values of the nitrogen dioxide concentration

IV. Mathematical Model for Modelling the Pollution of the Atmosphere by Harmful Emissions from Vehicles

Regular measurement of atmospheric pollution by harmful emissions vehicles and establishment actual concentrations pollution requires a huge amount resources, in particular gas analyzers, special equipment for ecological monitoring systems, which is unrealistic even for countries with high economic levels and social development. An alternative to this is the development monitoring systems with mathematical models in their composition, which, based on a limited sample data, make it possible to predict time changes the concentrations harmful emissions. In this case, it is expedient to use interval discrete dynamic models, and to identify them based on the analysis of interval data, as shown in such works [2-5].

In order to construct the model, is necessary a set of experimental data. Within the scope of work, a mobile measurement unit, based on a personal computer and a digital gas sensor type DGS-NO_2 968-037, was used for their obtaining. Measurement was carried out at the crossroads of the streets Ruska str. - Zamkova str, in Ternopil city every second. In order to compensate for a random measurement error, which is normally distributed with zero mathematical expectation, the measured instantaneous values were averaged in a window with a duration of 20 minutes. The fragment measured values of the concentration of nitrogen dioxide, temperature, humidity and traffic intensity of cars, at the crossroads of the streets Ruska-Zamkova, Ternopil, with a discrete of 20 minutes, is given in Table 3.

TABLE 3. THE OUTPUT DATA FOR MODELING THE DYNAMIC OF NO_2 CONCENTRATIONS

Time	v^-_k	v^+_k	Tepm	Rh	Cars
0:20	0,0336	0,04545	4	73,534	168
0:40	0,0232	0,03147	4	73,834	152

TABLE 3 (CONTINUE)

1:00	0,01782	0,02411	4	73,6424	147
…	…	…	…	…	…
12:00	0,06925	0,09369	5	94,2149	711
12:20	0,07337	0,09927	5	94,3498	694
12:40	0,07474	0,10112	4	96,3429	681
13:00	0,07394	0,10004	4	95,8456	779
…	…	…	…	…	…
23:00	0,04608	0,06235	2	77,4495	254
23:20	0,04486	0,06069	2	77,9879	219
23:40	0,04478	0,06059	2	78,3345	196
0:00	0,04419	0,05979	2	78,1432	172

Further, a well-known structural identification method, built on the basis behavioral models of the bee colony [6, 7], was used to construct a mathematical model for predicting the concentrations harmful emissions [8, 9].

The using of the method involves the transformation of structures of interval discrete models by operators $P(\Lambda_{mcn},F)$, $P_{\delta}(\Lambda_{mcn},F)$, $P_N(F,I_{\min},I_{\max})$ and through holding selection procedures by operators D1(λ_s,λ'_s), D2(λ_s,Λ'_s) in order to provide the reduction on each iteration of the goal function values for optimization task of structural identification the interval discrete dynamic model[8].

As a result of using the structural identification method, an adequate mathematical model for predicting the concentrations of harmful emissions from vehicles was obtained:

$$\begin{aligned} \hat{v}_k &= 0.0365 + 0.3541\cdot\hat{v}_{k-1} \\ &+0.118\cdot\hat{v}_{k-1}\cdot\hat{v}_{k-3} + 0.5059\cdot\hat{v}_{k-1}\cdot u_{3,k}/u_{3,k-1} - \\ &-0.01544\cdot\hat{v}_{k-2}\cdot u_{3,k-1}/u_{3,k+1}, \end{aligned} \quad (1)$$

where k=4…72; $\hat{v}_k$ – the predicted concentration nitrogen dioxide value in k moment of time; $\vec{u}_3 = (u_{3,0,\ldots,}u_{3,k+1})$ – known input variables vector (the intensity of traffic flows).

Note, the concentrations of measured values of harmful emissions NO_2 (at points k = 0 ... 3) should be set as initial conditions in the interval ± 0,5%, for the modeling with using linear discrete equation (1).

As we see, the obtained mathematical model reflects the dynamics concentrations of nitrogen dioxide, with a discrete time value 20 minutes. To use it, it is sufficient to set initial values of the measured concentrations, the temperature and humidity forecast, which is not a problem at short time intervals (for example, in the interval of one day). Note that the finded model can be used to model the concentrations harmful emissions in other city dots, provided that the parameters of the model are clarified.

V. DESIGNING OF THE MONITORING SYSTEM'S ARCHITECTURE

Figure 4 shows the developed architecture of the software system for automation monitoring and visualization pollution the near-ground layer atmosphere by harmful emissions of vehicles. As can be seen from the figure in this typical architecture, there are three logical layers [10]:

1) user interface (visualization layer);
2) data processing (business logic layer);
3) data access layer.

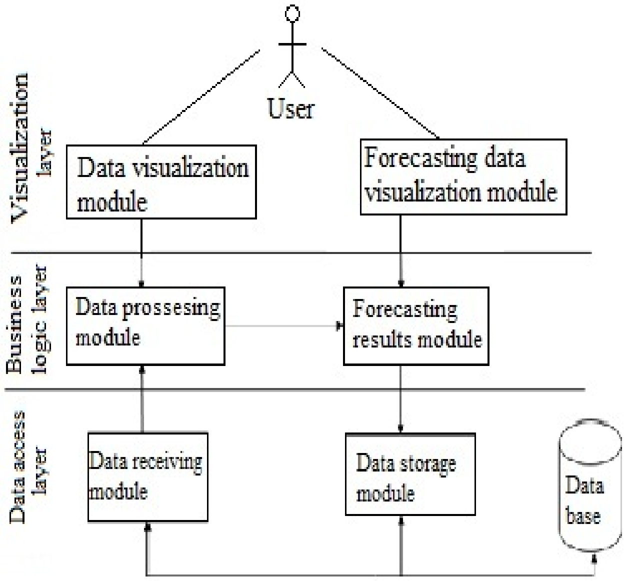

Fig.4. Architecture of the software system for modeling the air pollution by vehicles

At the first layer, the modules with which the user works and which are intended to visualize the results of the research are presented. This level does not have a direct connection with the database and the main business logic, in terms of security.

At the second layer, all data processing is carried out. This level is represented by the following modules:

- data processing module;
- forecasting results module – the main system module, which, implements the process of forecasting the concentration harmful emissions vehicles in a specific city point based on the model (1).

At the data access level, modules are stored, through which the business logic level interacts with the database using CRUD operations.

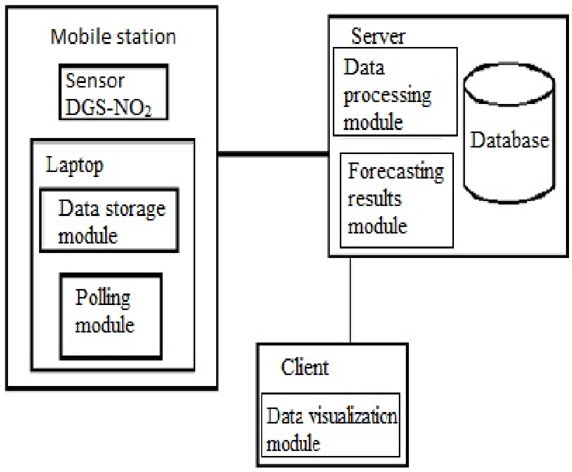

Fig.5. System modules placement

Figure 5 shows the system modules placement for modeling atmosphere pollution by vehicle. As can be seen from the figure, the modules are located on different hardware.

A mobile station measuring NO_2 level is based on a notebook with a Windows operating system and a sensor called "SPEC Sensors DGS-NO_2 968-037". The DGS-NO_2 968-037 sensor is equipped with an UART-to-USB adapter, which allows you to connect it to your computer through the USB interface. For the correct sensor operation, it should be installed CP210x USB to UART Bridge VCP driver and terminal TeraTerm, on the laptop.

The sensor connection is carried out similarly to the previous case - via the USB interface. Measurement of instant concentrations of NO_2 is carried out every second. Data is recorded in a log file and transmitted to the server using a Wi-Fi connection.

The monitoring station is the server where the NO_2 measured concentrations are located, software for constructing mathematical models to forecast the time distribution of the indicated concentrations.

Also, the monitoring station implemented a server part web-based system to display the modeling results and archive data on the level concentrations harmful emissions vehicles in the atmosphere city Ternopil.

On the user's side, deployed a client-side web-based system that lets you monitor real-time emissions of nitrogen dioxide into the air.

To use the website, the user will need to access the Internet from the computer that is used, and any web browser that supports HTML5 and CSS3 standards is installed.

Figure 6 shows the look of the home page of the website.

Fig.6. The website main page

As shown in Figure 6, in order to allow the user to view the concentration data dioxide, he must select from the dropdown list the control point (street crossings), after which a concentration graph of the daily cycle of NO_2 will be displayed before it.

VI. Conclusion

The paper considers an approach for modeling a daily cycle of changes in nitrogen dioxide concentrations within a road single section. A method is developed for operative and automated obtaining of experimental data. Designed and developed software architecture for modeling the atmosphere pollution by harmful emissions of vehicles. The proposed method approbation for the receipt and processing experimental data on NO_2 concentrations, as well as software developed on the example of modeling the distribution harmful emissions in the city of Ternopil.

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