Software for Modelling the Air Pollution by Vehicles
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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).

The microbiological analysis of 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 NO₂ / NO converters produce analytical signals for NO, NOx and NO₂ simultaneously or sequentially. Table 1 gives a comparative characteristics NO₂ measuring devices.

<table>
<thead>
<tr>
<th>Name</th>
<th>DGS-NO₂ 968-037</th>
<th>Ug-2</th>
<th>Polar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price(UAH)</td>
<td>2100</td>
<td>4000</td>
<td>6000</td>
</tr>
<tr>
<td>Dimensions</td>
<td>44.5 x 20.8 x 8.9 mm</td>
<td>110 x 105 x 200 mm</td>
<td>148 x 164 x 80 mm</td>
</tr>
<tr>
<td>Measurement error</td>
<td>15%</td>
<td>25%</td>
<td>20%</td>
</tr>
</tbody>
</table>

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-NO₂ 968-037 sensor as it many advantages, such as low price, high resolution etc.

Fig. 1 shows the general view of the sensor DGS-NO₂ 968-037.

Fig.1. General view of the sensor DGS-NO₂ 968-037
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 str., 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°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 NO2 is maximal.

Table 2 shows the averaged NO2 concentrations obtained over an hour by measuring the concentration of the DGS-NO2 968-037 sensor. The format of the output is: Sensor number [XXXXXXXXXXX], PPB (Part per billion) [0:999999], Temperature (°C) [-99:99], RH [0:99], RawSensor [ADCCount], TempDigital, RHDigital, Day [0:99], Hour [0:23], Minute [0:59], Second [0:59].

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>NO2, ppb</th>
<th>NO2, ppm</th>
<th>NO2, mg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>20,9</td>
<td>0,0209</td>
<td>0,0423</td>
</tr>
<tr>
<td>20</td>
<td>11,15</td>
<td>0,01115</td>
<td>0,02259</td>
</tr>
<tr>
<td>30</td>
<td>8,683333</td>
<td>0,00868333</td>
<td>0,01759</td>
</tr>
<tr>
<td>40</td>
<td>14,76667</td>
<td>0,014766667</td>
<td>0,02992</td>
</tr>
<tr>
<td>50</td>
<td>9,5</td>
<td>0,0095</td>
<td>0,0192</td>
</tr>
<tr>
<td>60</td>
<td>3</td>
<td>0,003</td>
<td>0,00608</td>
</tr>
</tbody>
</table>

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.
TABLE 3 (CONTINUE)

<table>
<thead>
<tr>
<th>Time</th>
<th>CO</th>
<th>NO2</th>
<th>CO2</th>
</tr>
</thead>
</table>
| 1:00  | 0.01782 | 0.02411 | 4
| 12:00 | 0.06925 | 0.09369 | 5
| 12:20 | 0.07474 | 0.09927 | 5
| 12:40 | 0.07394 | 0.10004 | 4
| 13:00 | 0.07487 | 0.10112 | 4
| 22:00 | 0.04608 | 0.06235 | 2
| 22:20 | 0.04486 | 0.06069 | 2
| 23:40 | 0.04478 | 0.06059 | 2
| 0:00  | 0.04419 | 0.05979 | 2

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 \( P(\Lambda_{mcn}F) \), \( P_0(\Lambda_{mcn}F), P_N(F, I_{min}, I_{max}) \) and through holding selection procedures by operators \( D_1(\lambda_\lambda'), D_2(\lambda, \lambda') \) 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:

\[
\hat{v}_k = 0.0365 + 0.3541 \cdot \hat{v}_{k-1} + 0.118 \cdot \hat{v}_{k-1} \cdot \hat{v}_{k-3} + 0.5059 \cdot \hat{v}_{k-1} \cdot u_{3,k} / u_{3,k-1} - 0.01544 \cdot \hat{v}_{k-2} \cdot u_{3,k-1} / u_{3,k-1},
\]

where \( k=4...72; \hat{v}_k \) – the predicted concentration nitrogen dioxide value in \( k \) moment of time; \( \hat{u}_3 = (u_{3,0}...u_{3,k-1}) \) – 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 \( \pm 0.5\% \), 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.
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\textsubscript{2} level is based on a notebook with a Windows operating system and a sensor called "SPEC Sensors DGS-NO\textsubscript{2} 968-037". The DGS-NO\textsubscript{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\textsubscript{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\textsubscript{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 Ternopol.

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.

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\textsubscript{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\textsubscript{2} concentrations, as well as software developed on the example of modeling the distribution harmful emissions in the city of Ternopil.

REFERENCES