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METHOD AND TECHNOLOGY FOR MONITORING AND FORECASTING THE ATMOSPHERIC AIR CONDITION BY MEANS OF UNIVERSAL INFORMATION-MEASURING SYSTEM WITH THE APPLICATIN OF MOBILE DEVICES

The paper considers urgent problem of monitoring and prediction of the atmospheric air condition in the city, where the main factor of pollution is motor vehicle emissions on the highways. The developed new method and technology for solving this problem are based on the application of a universal information-measuring system, built on the basis of mobile devices for monitoring and controlling the atmospheric air condition and the sources of its pollution. An experiment to test this technology, conducted in the streets of Vinnytsia, has confirmed its efficiency.

Key words: *ecological monitoring, atmospheric air, motor transport, information-measuring system, mobile devices, GIS, Vinnytsia.*

Introduction and presuppositions

At present there exists a problem of air pollution in the cities. In Ukraine there is a tendency towards main air pollutants being not stationary, but mobile sources of emission, mostly motor vehicles. In order to reduce this impact, especially in the most vulnerable places (near hospitals, kindergartens, educational institutions, nature reserve fund objects (NRF), etc.), it is necessary to conduct a serious feasibility study of possible solutions. Among initial steps dependence between the quantity of transport means (TM) and content of the pollutants in atmospheric air should be established, which would make it possible to evaluate the efficiency of certain management decisions.

In the international practice a rather wide circle of enterprises, non-commercial institutions, state international ecologic institutions and agencies have been engaged in theoretical and practical aspects of the environment monitoring [1, 2].

However, the network of the atmospheric air condition monitoring sites is not sufficiently wide in the cities. Besides, it is difficult to synchronize data from these sites with the entire quantity of TM, which are the air pollution sources. In order to solve these problems, a universal information measuring system (IMS), based on the application of mobile devices, could be used for automation of all monitoring data processing operations. Such IMS could be installed on TM for performing observations directly in transport flow synchronically with monitoring the quantity of TM in this flow.

One of the problems of such observations is their low reliability since he environment condition monitoring data and meteorological parameters will hardly be sufficient to construct and identify a complex physical-mathematical model of transfer of gases in the atmosphere. Different approaches to data aggregation as well as statistical methods should be used.

The entire complex of these problems has not been solved yet for the case when it is necessary to conduct rapid measurements of the definite atmospheric air condition indices in definite places synchronically with monitoring the sources of its pollution, to provide their rapid processing and, at the same time, to make the technology less expensive by the application of universal computer mobile devices. Therefore, this work deals with the development of technology for planning observations and processing the obtained data.

The aim of the research is to develop the method and technology for atmospheric air condition monitoring by means of universal-information measuring system with the application of mobile devices, i. e. of the system, where all the processing operations are performed on the basis of universal mobile computer devices (smartphones, tablets, netbooks, notebook, etc.). It is also important to provide synchronization of the atmospheric air condition monitoring data with the data of observations over the sources of its pollution.

The idea of solving the set problem

As it was mentioned above, for rapid atmospheric air monitoring it would be optimal to use information-measuring system (IMS), installed on a vehicle (automobile, tram, bicycle, multicopter, unmanned aerial vehicle, etc.). In order to provide wide application of the technology, it is expedient to use IMS, based on modern mobile devices, e.g. smartphones for geolocation of the observation place as well as storing, processing and transmitting data to the server, while for data collection from the sensors Arduino, RaspberryPi and their analogs could be used [3]. Such technical realization of IMS for on-line monitoring is cheaper and more wide-spread than known industrial analogs, which would provide wider range of applications and collection of large amounts of data, especially with the involvement of active community.

In order to solve the main problem related to measuring the atmospheric air condition in a city and revealing negative tendencies, problematic aspects and, ideally, also causes of air pollution, a corresponding information technology for collection and processing of the monitoring data should be developed.

Certainly, observations and forecasting of the atmospheric air pollution have been performed in many countries for dozens of years. The following most-spread models of forecasting the air condition quality could be distinguished: SOSE, TAPM, ОНД-86 [4, 5]. Main common factor of these models is large amounts of data required for adequate air pollution evaluation. And, which is more important, some models require values of the pollutant concentrations in a stationary source of emission or the amounts of emission of industrial objects as initial data. At the same time, in the presented method of the atmospheric air quality evaluation motor transport, moving along the main city highways, is considered to be the main source of emission of dangerous substances.

To solve the set problem, the following procedure and technology are proposed:

I. Determination of the conditions of performing observations and their planning.

Determination of K indices $F_k, k = \overline{1,K}$, which should be monitored, choice of sensors and their connection to IMS.

Choice of the optimal route, where could be problematic places and sources of extraordinary pollution, and its division into M characteristic sections with the length L_j, $j = \overline{1,M}$. Computation of the total driving route of TM with IMS:

$$L = \sum_{j=1}^{M} L_j .$$

Choice of the optimal driving speed $V_j, j = \overline{1,M}$ of TM depending on response time of the sensors and minimal number of measurements on each section (by the slowest among them with response time $t, V_j = \dfrac{L_j}{t \cdot N_j}$).

Defining speed V_j, length of section L_j, interval t between the sensor measurements and determining the number of observation points L_j, $j = \overline{1,M}$.

Determination of meteorological data (wind strength and direction, precipitation, etc.)

Determination of the location of sensors on TM.

II. Collection of observation data.

Using sensors, array of indices $F_{k,j}$, $k = \overline{1,K}$, $j = \overline{1,M}$ is formed.

Using GPS sensor, coordinates of the sequential location places on all sections with maximal response time are determined, $U_q, q = \overline{1,Q}$.

Using a video recorder, the number of such stationary and mobile pollution sources on the route is determined, which could influence air condition along the chosen route of the vehicle with sensors, $R_j, j=\overline{1,M}$.

Saving the collected and digitized data to a carrier.

III. Processing the data of observations.

On the basis of average speed V_j of the vehicle on each section linear coordinates $F_{k,j}$ of the places, where measurements were performed, are determined.

Geocoding of geolocation results by means of geoinformation systems (GIS), building the vehicle driving trajectory on the electronic map of the area and identification of the spatial coordinates U_q for each linear coordinate from p. 1.

The number of stationary and mobile potential pollution sources on each section is determined.

The number of those vehicles is calculated, which were moving in the same direction and were on the section, when vehicle with IMS was at the beginning of this section (Fig. 1).

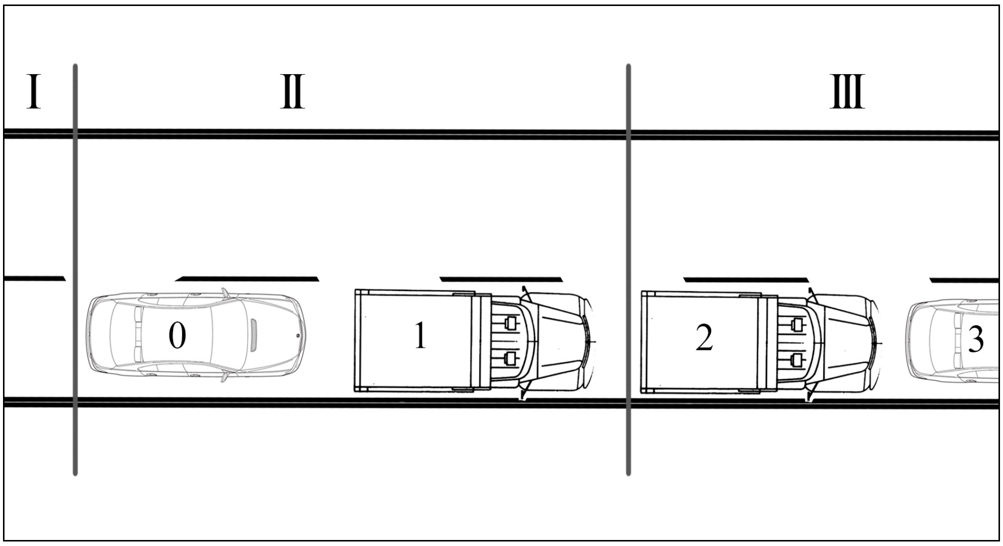

Fig. 1. Schematic presentation of the principles of measurements on the section with CO concentration in the atmospheric air of the road

Theoretically, when measurement results are processed, the system operator should count not only pollution sources on this section, but also those of neighboring sections, although their influence, in the first approximation, could be neglected since TM themselves cause movement of the air masses even without wind. So TM, which have just passed the given road, are the main sources of pollution on it. Certainly, in many cases it is not so, and then the calculation methodology on this section could be changed accordingly. Also, in the first approximation, TM with IMS is not considered to be a source of pollution (with the exception of cases, when it had to stop or brake for certain reasons. and then it should be counted because exhaust gases were “catching up” IMS sensors on this vehicle). E. g., when pollution sources from section II were counted, the operator referred only TM number 1 to the pollution sources (TM № 0 is the vehicle, where sensors are installed).

VI. Building regressive dependence between CO monitoring data and the quantity of TM with the application of GIS technologies and statistical methods.

Exporting the obtained data of monitoring F_j and R_j for building the array of point objects on the electronic map of the area.

Building the surface matrix by the method of weighted average interpolation, logarithmic method or by the method of cricking.

Averaging of F_{avj} index concentration on each section.

Performing aggregation of TM driving conditions by means of transition to the reduced quantity of TM R' on the sections, taking into account corresponding coefficients:

$$R' = R \cdot k_r \cdot k_d \cdot k_m ,$$

where R – actual quantity of TM; k_r – coefficient that takes into account reduction or increase of CO emission from TM depending on the character of relief; k_d – coefficient that takes into account reduction or increase of CO emission from TM due to road signs (stopping in front of crossing, speed limitations, etc.); k_m – coefficient, taking into account increased CO emission from TM relative to averaged TM because this TM is a truck, a bus, a car, etc.

Determination of R_j index, $j = \overline{1, M}$, is performed in a semiautomatic mode. The system operator, reading the data from video recorder, should calculate the value of R_j index for each section with the length L_j. To simplify this operation, special software for synchronization of the video with GIS was developed by A. Krylyk, a VNTU student.

Performing correlative analysis between the average concentration of F_{avj} index on each section and average number of automobiles $R_j^{'}$ on each section.

Building regressive dependencies between F_{av} and R', integral for all sections, which would make it possible to predict air pollution in the city.

Evaluation of the measurement and computation errors.

Analysis of the errors. Determination of the smallest measurement error.

Viewing the predicted loading level of the highways with the application of «Google.Traffic» or «Яндекс.Пробки» and forecasting pollution distribution throughout the city.

Technology application example

The authors have developed a universal information-measuring system for promt ecological monitoring with the application of mobile devices [6]. It was adapted to CO concentration measurements in the atmospheric air. Observations to be performed over the motor roads in the city of Vinnytsia have been planned.

Driving route of TM with IMS in the city was chosen so that it would pass near the places which are the most vulnerable to pollution (NRF objects of various levels, parks, hospitals, educational institutions, etc.). Two routes were chosen. The first route was around the territory of Vinnytsia National Technical University, the second one – along Khmelnitske Shose street (from VNTU territory to Pervomayskaya street) and then around Central Park of Culture and Recreation – along Pervomayskaya street from its intersection with Khmelnitske shose street up to the ambulance station. At the time of the experiment meteorological conditions were as follows: wind of the north-west direction with the speed of 2 – 3 m/s, no precipitation. During the experiment the number of automobiles on the highways was registered by means of video recorder, which has enabled taking into account the influence of the motor transport on the degree of atmospheric air pollution.

Monitoring data were interpolated by the logarithmic method (Fig. 2) and the method of cricking (Fig. 3 – 5).

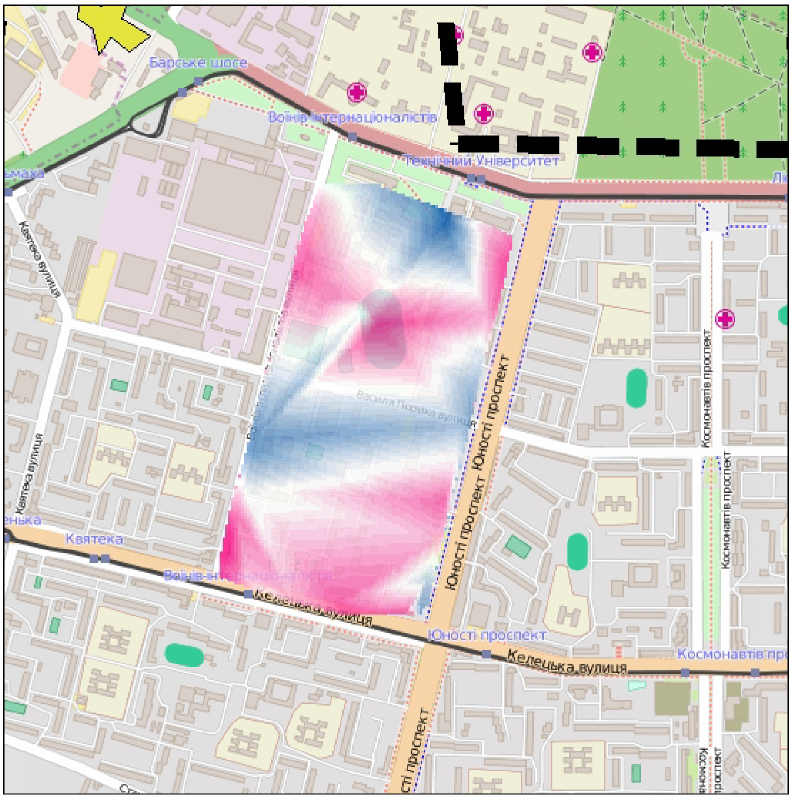

Fig. 2. Interpolation of the data of monitoring the territory around VNTU (Barskoye shose street, Voinov-Internationalistov street, Keletskaya street) by logarithmic method

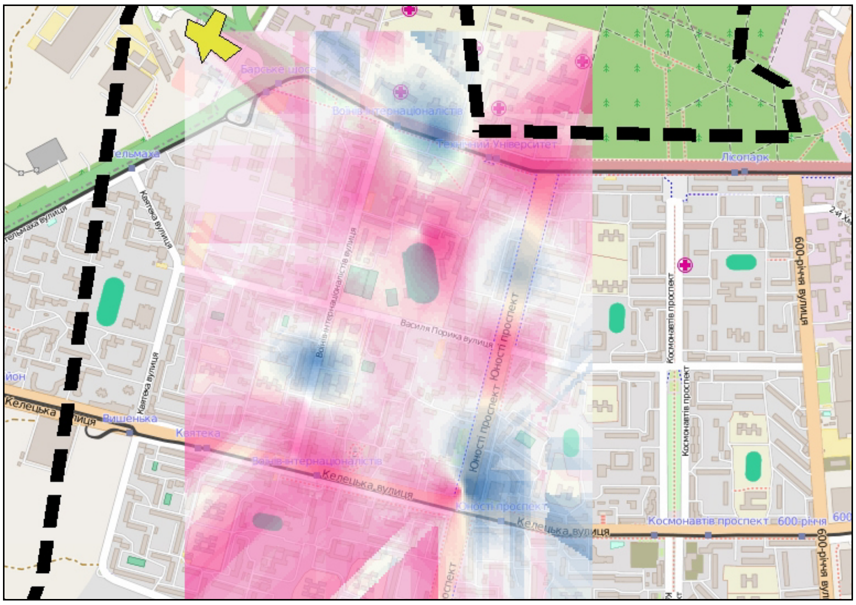

Fig. 3. Interpolation of the data of monitoring the territory around VNTU using the method of cricking

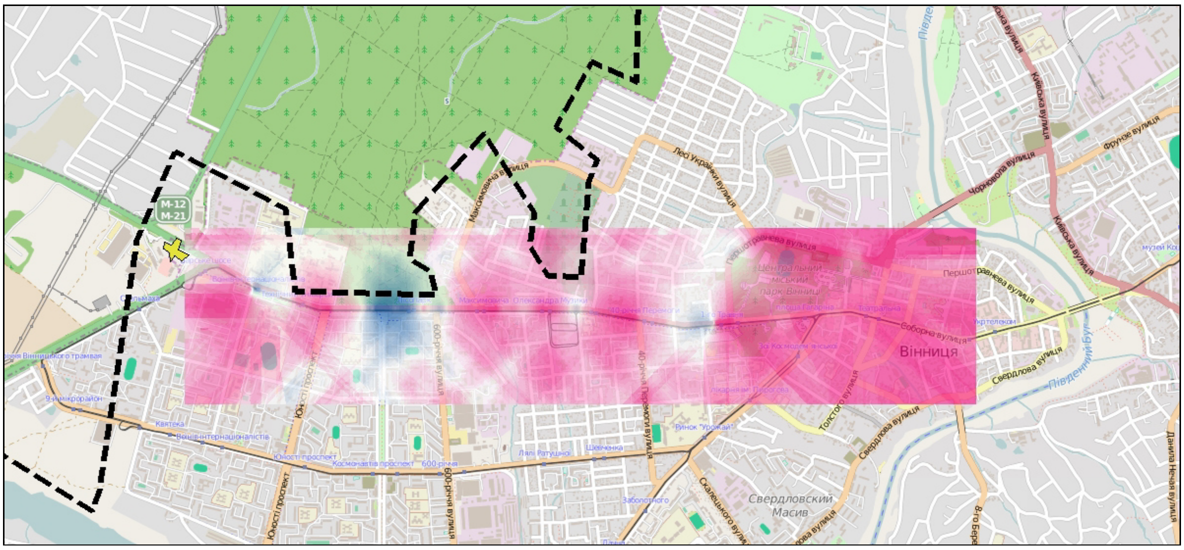

Fig. 4. Interpolation of the second route monitoring data by the method of cricking

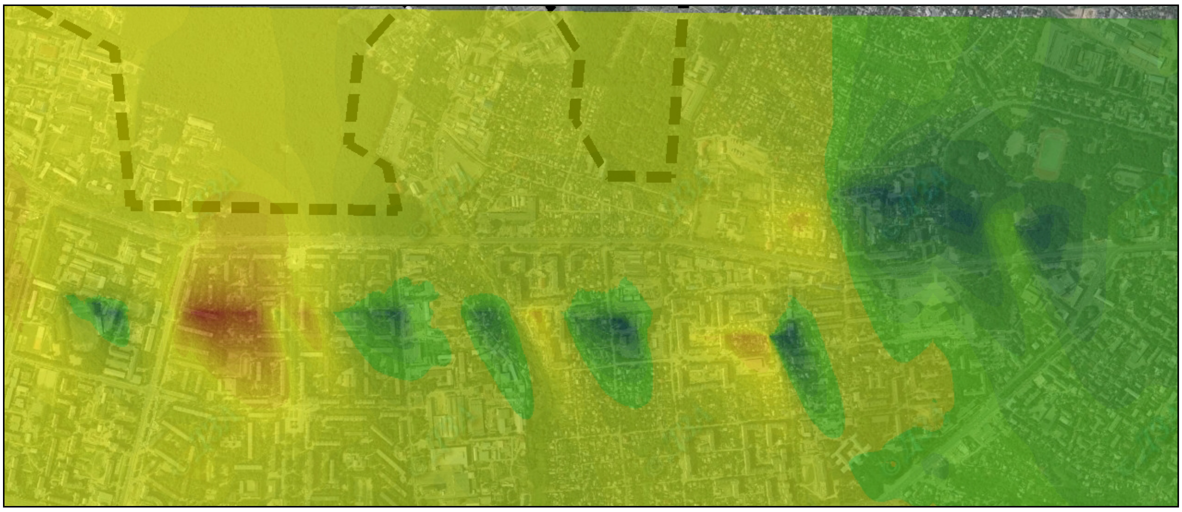
Fig. 5. Matrix of CO concentration in the atmospheric air of Vinnytsia along the second route

On the basis of the obtained experimental data the following recommendations can be given:

- to increase the amount of the system input data;
- to break the total way L into greater number of sections L_j;
- to improve synchronization of the sensors interaction.

In order to implement the last recommendation, it is proposed that multiplicity coefficient of the operation interval for the sensors of different types should maximally approach an integral number. Then we should determine response time of the sensors CO (T_U) and GPS (T_W). Thus,

$$v = \frac{T_U}{T_W}.$$

For the second route a regression dependence between the data of F_{av} and R' monitoring with the application of GIS-technologies and the data obtained by statistical methods according to the proposed technology has been built. In particular, F_{avj}, R'_j were calculated and correlation analysis of the dependence of CO distribution concentration F_{av} on R' was conducted for the entire route (Table 1).

Correlation coefficient value exceeds 0, 9. Therefore, there is a strong stochastic relationship between CO distribution concentration and the reduced quantity of TM in the streets of the city.

Table 1

CO concentration dependence on the reduced quantity of TM on the second route sections

Section number j	Average concentration of CO F_{avj}	Reduced quantity of automobiles R'_j
1	196	32
2	156	22
3	133	12
4	195	28
5	261	48
6	174	21
7	156	18
8	125	18
9	160	25
10	106	15
11	163	23
12	199	27
13	134	18
Correlation	0,93	

Presence of the correlation makes it possible to build the dependence between F_{av} and R', which enables prediction of air pollution in the city. Let us perform identification of this dependence by three types of regression; linear (Fig. 6), logarithmic and exponential.

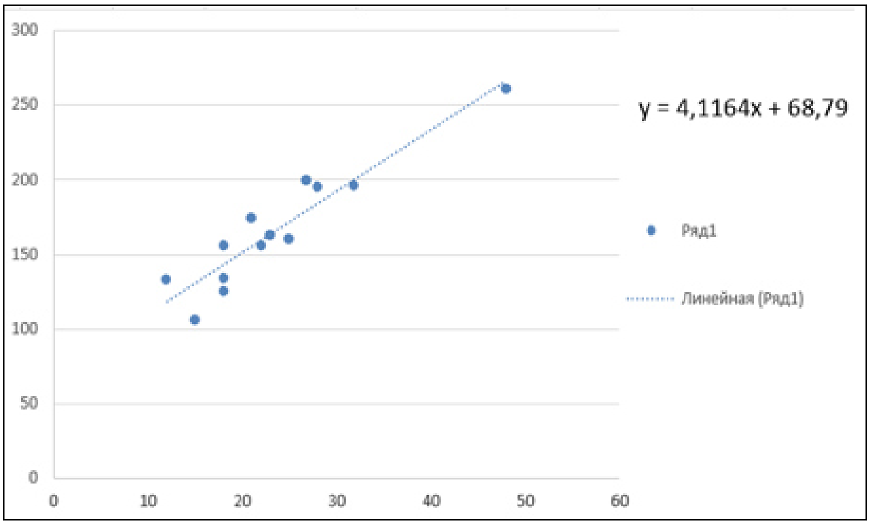

Fig. 6. Linear dependence between F and R

Then we determine errors of the linear, logarithmic and exponential dependences (Table 2).

Y2		DY2
200,515		4,5148
159,351		3,3508
118,187		14,8132
184,049		10,9508
266,377		5,3772
155,234		18,7656
142,885		13,1148
142,885		17,8852
171,7		11,7
130,536		24,536
163,467		0,4672
179,933		19,0672
142,885		8,8852
		153,428
	Похибка2	7,10973

Fig. 7. Error of the linear dependence

Table 2

The obtained values of errors

	Linear dependence error	Logarithmic dependence error	Exponential dependence error
Value, %	7,1	8,2	7,8

After analysis of the experimental data errors we could make a conclusion that the best prediction of the air pollution in the city could be made using linear dependence between F_{av} and R' since approximation error of this dependence is smaller than approximation errors of logarithmic and exponential dependences.

Conclusions

A new method and technology are proposed for monitoring and evaluation of the atmospheric air condition, the main pollution factor of which is motor transport emissions on the highways of the city. The main distinguishing feature of the proposed method as compared with the existing analogs is as follows: data obtained by means of the universal information-measuring system, which is based on mobile devices installed on the vehicle, are used as input parameters. In addition, the technology provides the possibility to synchronize the data of atmospheric air condition monitoring with the data of its pollution sources monitoring. This makes it possible to reduce considerably the data collection time and to increase the amount and relevance of the monitoring data as compared with the analogs. Due to the universal format of the obtained computation results, the proposed method also enables visualization of the quality indices of the atmospheric air condition at numerous IMS and, if necessary, identification of the regressive model and its application for air quality prediction depending on the expected quantity of transport means and other conditions.

The proposed technology opens wide possibilities for social, state and research institutions to perform initial independent prompt air condition monitoring in the city, which, in its turn, will give grounds for refining measurement results using specialized measuring equipment. Wide-scale monitoring will enable identification of problematic places of ecologic nature as well as of the most vulnerable infrastructure objects (hospitals, schools, etc.), nature reserve fund objects and elaboration of recommendations as to improvement of ther air condition in the city. An important advantage of the developed technology is the possibility to use the technology for other purposes: the waters condition monitoring as well as of other components and objects of the environment, loading level of the highways, municipal and commercial transport traffic, etc.

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