Methods and means of searching for carbon monoxide source (CO) using small aircraft

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Abstract. The article considers the method and means of early detection of the air pollution source on the example of carbon monoxide (CO). The relevance of the study is determined by the method of searching for CO source using modern robotic aircraft. A comparative analysis of environmental monitoring using mobile laboratories and stationary observation points was made, integral indicator values of expert assessment of the quality indicators of environmental monitoring of the air atmosphere were calculated. The advantages of the method for detecting the carbon monoxide source over existing ones are substantiated.

1. Introduction

The health of the city's population depends on many factors, among which the state of the environment takes a significant place. Air pollution with toxic gases is one of the reasons for the accumulation of harmful mutations in the human body, which will be inherited by subsequent generations [1]. In large cities, the consequences of atmospheric air pollution can lead to an increase in the incidence rate of oncological, allergic and cardiovascular diseases among the population. In this regard, the systems of environmental monitoring are the most important scientific and practical mechanism for implementing the state environmental policy.

To solve this problem and make timely decisions on preventive and protective measures aimed not only at protecting the environment, but also public health, it is necessary to increase the efficiency and accuracy of detecting sources of environmental hazard. Therefore, a method is proposed for the search and early detection of a CO source using autonomous small-sized aircraft [2] equipped with analytical attachments that allow one to quickly, in real time, carry out remote-contact monitoring and assess the risk and environmental situation, thereby reducing the response time of special services to eliminate the source of pollution and eliminate the consequences [3].

Existing emergency emission control systems, which are presented in the form of stationary posts equipped with the necessary equipment and automatic gas analyzers, do not fully allow one to determine with the necessary accuracy the location and coordinates of pollution source, the initial parameters of the emission, weather conditions and, accordingly, obtain sufficient and prompt information for the adoption of proper measures. There is another monitoring method using a technical service employee, but this method has a number of disadvantages, the most important of which is the threat to human life and health.
Thus, the development of this method of the environmental monitoring system using modern aircraft robotic means makes it possible to increase the efficiency of environmental monitoring of atmospheric air and take appropriate measures to eliminate the emergency.

2. Materials and methods
The method under study is based on the use of small aircraft, the control system of which is based on the use of dynamic models and traffic control algorithms to increase the concentration of carbon monoxide (CO), measured by an onboard gas analyzer, for determining the coordinates of the pollution source.

To detect sources of pollution with toxic gases such as carbon monoxide, small-sized aircraft are effective, allowing for autonomous vertical take-off, hovering over an object, horizontal flight both in a circle and in a straight line.

Let us consider an example of searching and planning the trajectory of movement to the source of pollution [4]. The CO concentration is used as the main criterion, which is recorded by the onboard gas analyzer of the aircraft. The increase in concentration is a defining feature for the movement of the mobile platform towards the source of pollution (figure 1). For example, we use an ignition source with the release of a large amount of carbon monoxide (CO) [5].

![Diagram](image)

Figure 1. Scheme of the movement of the aircraft to the carbon monoxide source (CO).

The takeoff takes place from any horizontal surface to a certain height $H$ in accordance with the flight task. Further, to select the direction of movement, the device starts moving in a circle with radius $R$, according to the following law: $Z=H$, $X=R\cos(\Omega t)$, $Y=R\sin(\Omega t)$, where $R$ is the radius of the flyby area, $\Omega R$ is the maximum speed of the center of mass along the trajectory. The trajectory equation has the form: $X^2 + Y^2 = R^2$.

The CO relative concentration when moving away from the source of carbon monoxide is determined by the formula: $C=C_x/C_{max}$, where $C$ is the CO relative concentration; $C_x$ is CO concentration at a distance $x$ from the source; $C_{max}$ is CO concentration in the source. The distribution of CO in space is affected by the speed of air masses in the area of the ignition source. At zero speed
of air masses, the decrease in CO concentration depending on the distance can be determined from the graph (figure 2) obtained by experiments [6].

As shown earlier, after initialization, an aircraft with a gas analyzer takes off to a certain height and then moves in a circle with a radius $R$, the value of which was found experimentally in previous works [7]. The radius $R=5m$ is considered optimal. After finding the maximum concentration gradient, there is a movement in a straight line in the direction of increasing concentration. Thus, the trajectory of the mobile gas analyzer is a set of circles and straight-line segments. The process of movement is completed after the CO concentration on the circle does not change practically when moving in a circle. That is, the CO source is inside the circle and its position is determined with an error equal to the radius of this circle $R$ (figure 3).

This method allows us to use one gas analyzer installed on a small-sized aircraft to determine the coordinates of the CO source. Where possible, it is suggested that mobile GPS be used as a means of measuring distances. The normalized permissible error of the measuring instruments used in this method should be considered as the error in measuring the distance (the location of the gas analyzer) and CO concentration.

To monitor air pollution in an industrial cluster, automated monitoring systems with software and mathematical support are currently used. As a result of exploratory analysis, we determine the optimal coordinates of observation posts in such a way that, by interpolating data, we can build a map of the ecological state of the atmosphere, and we also determine the coordinates of sources of atmospheric
air pollution. Despite the fact that there are quite powerful software tools for analyzing air pollution, the mathematical models used do not have sufficient accuracy, and the stationary observation posts used cannot provide high accuracy, due to changing wind speed and direction, limited by the height of the location of stationary sensors.

3. Results
To monitor air pollution in an industrial cluster, automated monitoring systems with software and mathematical support are currently used [8]. As a result of exploratory analysis, we determine the optimal coordinates of observation posts in such a way that, by interpolating data, we can build a map of the ecological state of the atmosphere, and we also determine the coordinates of sources of atmospheric air pollution. Despite the fact that there are quite powerful software tools for analyzing air pollution, the mathematical models used do not have sufficient accuracy, and the stationary observation posts used cannot provide high accuracy, due to changing wind speed and direction, limited by the height of the location of stationary sensors.

The quality indicators of environmental monitoring were assessed based on the opinions of experts; the selection of experts was carried out on the basis of their competence. Using this method, six experts were included in the expert group. At the next stage, criteria were formed of environmental monitoring of atmospheric air and their indicators of relevance, which was evaluated on a ten-point ordinal scale.

Below is a diagram of comparison of environmental monitoring quality indicators for three methods of environmental monitoring (figure 4):

- Mobile laboratory (ML).
- Stationary observation points (SOP).
- An aircraft with a gas analyzer or a mobile gas analyzer (MGA).

An integral criterion \( I_j \) was also developed, which was obtained by visual assessment of the area described by the corresponding curves in the diagram (figure 5), and determined by the formula:
\[ I_j = \sum_{i=1}^{11} \frac{K_p^j}{K_p^{\text{PRED}}} \cdot \xi_{ij} \]  

(1)

Where \( j = \text{ML, SOP, MGA} \); \( \xi_{ij} \) is indicator corresponding to expert assessment \( j \).

The values of the integral indicator of expert assessment of the quality indicators of environmental monitoring of the air atmosphere are given below (table 1).

**Table 1. Integral indicator of expert assessment of quality indicators of environmental monitoring of the air atmosphere.**

| Integral indicator | Mobile laboratory | Stationary observation points | Mobile gas analyzer |
|--------------------|-------------------|-------------------------------|---------------------|
| \( I_j \)          | 44.50             | 28.75                         | 64.275              |

4. Discussion

Measurement errors in environmental monitoring are usually subject to low requirements: for stationary observation points it is no more than ±25, for mobile laboratories - no less than ±15. MGA can provide measurement accuracy of at least ±10.

The criticality of environmental monitoring to the relief is of great importance, therefore, according to this indicator MGA has advantages over both stationary observation points and a mobile laboratory. The frequency of sampling depends on many factors. At stationary observation points, it is usually 4 times a day [9], and they have certain advantages in this indicator, both over a mobile laboratory and over a small-sized aircraft.

Interpolation of environmental monitoring data requires not only appropriate software, but also a sufficient number of measurements per unit area of the controlled surface, which ensures the reliability of interpolation and the solution of the inverse problem. The data transfer rate is ensured by the presence of encoding and transmitting devices. If all stationary observation points operate in automatic mode, then they are comparable in this indicator with MGA, but stationary observation points do not always have such capabilities, therefore this indicator is underrated.

It is known that the concentration of atmospheric pollutants varies with distance from the earth's surface and that some part of the controlled territory is inaccessible both for the installation of observation posts and for a mobile laboratory, therefore, MGA has a significant advantage in this indicator compared to known monitoring methods.

In terms of criticality to wind speed, it is due to the fact that with a strong wind the pollutant spreads over large areas and can go beyond the controlled area. The optimal wind speed for filling the atmosphere of an industrial cluster with pollutants is 1.2 m/s. This wind speed is also optimal for working with MGA [10].

5. Conclusion

This study considered a method for detecting carbon monoxide source (CO) using modern robotic means, namely small-sized aircraft. To achieve this goal, a method for improving environmental monitoring in comparison with existing ones is proposed, a comparative characteristic is given, and an integral indicator of expert assessment is calculated.

Further development of this method will significantly reduce the time for detecting sources of toxic gases, as well as improve the accuracy of detection, which will allow timely implementation of all necessary measures to protect the population and territory from emergency situations.

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