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Some aspects of adaptation of measuring instruments for instrumental emission control using UAVs

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Abstract. The study is devoted to the problem of adapting measuring instruments regulated for inventory of industrial facilities within the framework of environmental monitoring to be used on the basis of unmanned aerial vehicles (UAVs) for making measurements remotely in real time. The research considers the possibility of modifying existing measuring instruments by means of technical and software solutions as an alternative to the development of new specialized instruments integrated with the UAV design. Special attention is paid to the influence of external factors and conditions on the accuracy of measurements. In particular, the results of the experiment to study the oscillations of the sensitive elements of the device "Meteoskop-M" at different levels of vibration impact are analyzed. The measurement errors caused by dynamic loads are analyzed, and the necessity of using mechanical stabilization and damping devices, as well as algorithms of digital data correction is justified. On the basis of comparative analysis the advantages and disadvantages of the existing approaches to the implementation of the technology of inventory of industrial facilities using UAV-based measuring devices developed by the authors are revealed, the efficiency of their use in different operating conditions is considered. The conclusion is substantiated that the adaptation of serial devices through the implementation of engineering solutions taking into account the UAV flight conditions, in particular – vibration effects, is the most rational solution at the moment, and the accumulated experience will allow in the future to develop a new generation of measuring instruments integrated with the UAV carrier platform. The article is aimed at specialists in the field of environmental monitoring as it relates to the inventory of industrial facilities polluting the atmospheric air.

Keywords: environmental monitoring, pollutant emissions, inventory of industrial facilities, environmental pollution source, EPI, unmanned aerial vehicle, measurement tools, vibration effects, measurement accuracy

Authors' contribution. *I.I. Gavrilin* – conceptualization – ideas; resources – provision of educational materials and instruments; writing – review and editing – commentary and revision; project administration; *S.V. Simanovich* – methodology – development and construction of the experimental setup; investigation; data curation; writing – original draft; writing – review and editing. All authors have read and approved the final version of the manuscript.

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Некоторые аспекты адаптации средств измерений для инструментального контроля выбросов с использованием БПЛА

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Аннотация. Исследование посвящено проблеме адаптации измерительных приборов, регламентированных для инвентаризации промышленных объектов в рамках экологического мониторинга, к использованию на базе беспилотных летательных аппаратов (БПЛА) для проведения замеров дистанционно в режиме реального времени. Рассматривается возможность модификации существующих средств измерений посредством технических и программных решений как альтернатива разработке новых специализированных приборов, интегрированных с конструкцией БПЛА. Особое внимание уделено влиянию внешних факторов и условий на точность измерений. В частности, проанализированы результаты эксперимента с целью изучения колебаний чувствительных элементов прибора «Метеоскоп-М» при различных уровнях вибрационного воздействия. Проанализированы ошибки измерений, вызванные динамическими нагрузками, и обоснована необходимость использования устройств механической стабилизации и демпфирования, а также алгоритмов цифровой коррекции данных. На основе сравнительного анализа выявлены преимущества и недостатки существующих подходов к реализации разработанной авторами технологии инвентаризации промышленных объектов с использованием измерительных приборов на базе БПЛА, рассмотрена эффективность их использования в различных условиях эксплуатации. Обоснован вывод о том, что адаптация серийных приборов посредством реализации инженерных решений с учетом условий полета БПЛА, в частности вибрационных воздействий, является наиболее рациональным решением на текущий момент, а накопленный опыт позволит в будущем разработать новое поколение средств измерений, интегрированных с несущей платформой БПЛА. Работа ориентирована на специалистов в области экологического мониторинга в части, касающейся инвентаризации промышленных объектов, загрязняющих атмосферный воздух.

Ключевые слова: экологический мониторинг, выбросы загрязняющих веществ, инвентаризация промышленных объектов, источник загрязнений окружающей среды, ИЗАВ, беспилотный летательный аппарат, средства измерения, вибрационные воздействия, точность измерений.

Вклад авторов. *Гаврилин И.И.* – концептуализация статьи; ресурсы – предоставление учебных материалов и приборов; создание рукописи и ее редактирование – комментирование и пересмотр; администрирование проекта; *Симанович С.В.* – методология – разработка и создание экспериментального стенда; проведение исследования; администрирование данных; создание черновика рукописи; создание рукописи и ее редактирование. Все авторы ознакомлены с окончательной версией статьи и одобрили ее.

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Introduction

Unmanned Aerial Vehicles (UAVs) have nowadays shown highly effective applications in various human activities ranging from mapping and surveying to environmental monitoring and industrial emission control [1, 2].

Some authors note that the use of UAVs makes it possible to implement the methodology of measuring the characteristics of emissions from sources polluting the atmospheric air (APPI), located in inaccessible and dangerous places for humans, using signaling and analytical measurements of environmental characteristics by instrumental method, i.e. with high reliability [3]. The use of UAVs as a means of delivery of measuring instruments allows to carry out operational monitoring of environmental pollution in large areas and at different horizons, to determine the intensity of pollution by emissions of specific pollutants from industrial facilities. In this case, the efficiency of obtaining information allows to significantly reduce the time of its processing, and the accuracy of measurements significantly increases the objectivity of the environmental monitoring system, including in determining the zones of environmental pollution by specific harmful and (or) hazardous substances.

Thus, there is a method of complex monitoring of the regional environment described in the patent RU 2778495 C1, MPC G01W 1/00, published 22.08.2022, Bulletin No. 24 [4], which involves the use of a UAV-based instrument complex to measure and assess the state and changes in the atmospheric air of the region in order to form a database for further forecasting. Current parameters of emission sources are measured both remotely and by direct measurements, which allows to assess changes in the characteristics of the environment in dynamics. This method makes it possible to classify environmental objects according to their role, but only in the context of the carbon dioxide cycle: emission or absorption, including technogenic and natural sources, as well as anthropogenic factors.

The works of foreign researchers are mainly devoted to analysing the efficiency of UAV use in the field of geomonitoring, for example, when collecting data for the development of risk management systems in the oil and gas industry [5]. In this context, some domestic authors consider the efficiency, objectivity and prospects of using the ‘swarm’ technology (a group of UAVs) to determine the coordinates of the point source of atmospheric air pollution (SAAP) in case of accidental releases [6], excluding direct measurements. Thus, in the paper by Y.S. Legovich, a comparative analysis of existing solutions is carried out, emphasis is placed on the use of UAV group control models and the development of approaches based on the mathematical theory of planning and allowing to improve the algorithms of UAV coordination and navigation for accurate detection of SAAP.

The use of UAVs for measurements of environmental parameters is noted in the work of S.I. Yageldin, who proposes to use multi-rotor UAVs with integrated sensors for real-time recording of threshold indicators of temperature, pressure, humidity and gas concentration for environmental monitoring in industrial zones [7]. The proposed technology makes it possible to respond promptly and specifically to the zonal pollution of atmospheric air by emissions of industrial facilities, but does not provide for the determination of the intensity of emissions of harmful and (or) hazardous substances by a specific UAV.

A brief analysis of the capabilities of these technologies allows us to conclude that their main purpose is to determine the picture of pollution that has already taken place and to forecast its changes over large areas, but with low accuracy, sometimes hypothetically, and have no preventive potential to prevent possible pollution.

At the same time, it should be noted that the rules for classifying instruments and devices as measuring instruments and their use are regulated by federal executive authorities. Thus, according to the provisions of the Federal Law dated 26.06.2008 No. 102-FZ “On Ensuring Uniformity of Measurements”[1], a measuring instrument is recognised only as a technical means that allows to perform measurements in strict compliance with the regulated standards. The means of measurement is recognised only as a technical device, which allows to

[1] *On Ensuring Uniformity of Measurements. Federal Law dated 26.06.2008 No.102-FZ*. Available from: https://www.consultant.ru/document/cons_doc_LAW_77904/ (accessed: 06.11.2024).

make measurements in strict compliance with regulated metrological and technical requirements. These requirements apply to devices intended for carrying out both signaling and analytical measurements.

However, in our case it is necessary to take into account the devices technically capable of analytical measurements of parameters (temperature, velocity of gas-air flow, etc. as initial data for concentration determination) of the environment or, as a special case of the environment limited by the cross-section of the gas duct, – gas-air flow of emissions from the mouth of SAAP. It is obvious that only such measuring devices allow to perform quantitative assessment and analysis of aerodynamic characteristics of the gas-air flow in a wide enough range and with high accuracy, unlike detectors and sensors intended for signaling measurements for subsequent notification of critical (threshold) values of the environment state assessment or substance state analysis [8; 9].

For use within the framework of state regulation, a measuring instrument shall be type-approved and verified. In particular, the design of measuring instruments shall prevent unauthorised access and interventions that could distort the measurement results and shall have unique identification numbers.

Such requirements are relevant and objective, as the efficiency of fulfilment of environmental monitoring tasks directly depends on the reliability of the results obtained and accuracy of measurements in the process of primary data collection. Lack of accurate, comprehensive and timely primary data leads to distortion of information at subsequent levels of analysis, which may cause irrelevant and ineffective management decisions by state authorities [10].

At the same time, most modern instruments used in environmental monitoring and inventory of industrial facilities are originally designed for stationary use in laboratories or control facilities. In this case, the control of the instruments during operation, as well as the reading of measurement results, is carried out directly by a technician (operator).

The inventory technology proposed by the authors of the article implies the possibility of remote control of the devices by an operator (expert) with automatic reading of the data obtained during measurements and their subsequent transmission to the operator in real time. Further – fulfilment of a number of related requirements: mass and dimensional parameters of the devices, reliability and duration of their operation in flight mode, controllability, stability and coordination of UAVs in various weather conditions.

Undoubtedly, the existing modern technologies and technical capabilities allow to develop and use a fundamentally new instrumentation base, but this requires not only significant material resources and time, but also cardinal changes in the existing technologies of environmental monitoring and inventory, entailing, in turn, changes in the legal and regulatory framework governing the sphere of this activity.

The authors consider an alternative solution to this problem to be the adaptation of existing standard measuring instruments to be used on UAV hangers by implementing individual engineering solutions, which will compensate for the above-mentioned shortcomings of the instrumentation base and effectively use the instruments regulated by current technologies under new conditions.

To solve this problem, the authors of the paper investigate the technical aspects of adapting standard measurement devices placed in UAV suspensions for remote real-time use.

The aim of the study is to develop approaches for adaptation of measuring instruments for use in flight conditions.

To achieve this goal, the authors of the study set out the following tasks.

1. To analyse the main limitations of standard measuring devices when used in UAV suspension.
2. To identify external factors that may potentially affect the accuracy of measurement instruments.
3. To offer technical solutions for the protection of devices against external influences, including damping and stabilization.
4. To explore the possibilities of applying software methods for data correction, such as filtering and correction factors.
5. To provide recommendations on the selection of approaches for adaptation or development of new measurement tools.

Existing technical problems have been identified, the possibilities of physical modifications aimed at the operation of measuring instruments remotely, software solutions that ensure the efficiency and reliability of the use of the instrument complex based on UAV are under consideration, the ways to realize such possibilities through engineering solutions are proposed.

Materials and methods

One of the problems identified when using standard measuring instruments on an UAV platform is that little knowledge has been gained about the impact of vibrations and dynamic loads caused by the operation of engines and overloading during flight trajectory changes.

To study the influence of vibrations on the accuracy of measurements, an experiment was carried out using the device “Meteoskop-M” on a special stand simulating the conditions of operation of measuring devices in the conditions of flight of UAV. The study included an analysis of changes in airflow rate at different levels of vibration transmitted through the suspension structure. The results of the experiment will be presented in the next section.

The effects of these factors may lead to significant deviations in instrument readings, leading in turn to significant errors in the further use of these data in calculations. In addition, the difficulty is to ensure the stability of reading the data obtained when the orientation and altitude of the drone changes, which can also affect the quality and objectivity of the information received by the operator (expert).

Another important and, in fact, key problem is the unsuitability of regulated measuring instruments for remote control by an expert (operator). The standard instruments are designed and oriented to the operator's direct influence on their controls during operation. Using medical terminology, it can be said that the positioning of the device (its working organs) relative to the mouth of the gaseous (gas-dusting) SAAP stream, their management and data reading is done by a manual, which in the conditions of flight of UAV becomes impossible and, therefore, appropriate adaptation of the measurement means is required.

For this, as well as to compensate for the negative impact of external factors on the UAV and measuring instruments to ensure measurement accuracy through remote control of the instruments, reliability of receiving and transmitting data measurements to the operator (expert) is suggested:

- the combination of a set of additional devices with measuring instruments without structural modification of the latter;
- development and use of automated systems based on modern software and ICT;
- use of mathematical methods for data correction, in particular, correcting factors that allow to compensate the negative influence of external and anthropogenic factors on the work of the complex as a whole.

There is currently a regulated list of measuring devices that can be used on UAV based on metrological and mass-dimensional characteristics. However, in order for such measuring instruments to function properly in flight conditions, a number of technical modifications [11] are needed to:

- optimization of the design of the instrument cluster for its placement on the suspension to the UAV platform;
- remote control of the instrument controls, reading and transmission of measurement data;
- reducing the impact of vibrations, dynamic loads and other external factors that can significantly affect measurement accuracy.

In this context, the authors propose the following main elements of modifications.

1. Use of suspension with stabilization systems. The main design solution is to install measuring instruments on suspension using stabilization and damping systems, which ensure a stable position of the instrument in space and allow to compensate for the impact of inertial forces and vibrations. For this purpose, it is advisable to use in the design of the device to attach to the suspension shock-absorbing cuffs or damper joints, quenching the effect of small and frequent vibrations, which is especially important for high-sensitivity measuring instruments.

2. Weather shielding and protection. Measuring instruments installed on an UAV may be exposed to sudden changes in temperature, pressure and humidity. To ensure reliable operation of the devices in such conditions, their hydraulic and thermal protection with special materials with partial or complete sealing of the suspension housings is required.

3. Pads for manipulating controls. The conditions of remote control of measuring instruments determine the need for mechanical action on their controls – buttons, switches, sensors. For this purpose, it is advisable to use special pads with radio-controlled electromechanical manipulators (solenoids), which allow the required mechanical action on the controls and (or) the control elements. These pads are integrated with the UAV suspension and provide the operator with remote control and adjustment of instrument settings during measurement.

4. Reading instrument and data transmission system. The positioning of the instruments in the suspension of the UAV carrier platform requires a means to illuminate the measuring scales using a miniature video camera as a means to read the measurement results and transmit the video stream to the radio signal operator.

It is important to note that the individual elements of engineering solutions may vary depending on the type, purpose and design features of the measuring instruments in combination with software optimization.

Program optimization is an important part in ensuring the accuracy of measurements of the content and aerodynamic parameters of gas air flows. It allows not only to compensate for errors caused by external factors, but also to adapt the data for analysis and subsequent use.

In-flight anomalies may occur during data collection due to short-term changes in orientation caused by gusts of wind, heavy precipitation or abrupt manoeuvres. Software solutions, such as Kalman filters, allow to track and eliminate such anomalies, increasing the accuracy and reliability of the data obtained.

To improve the accuracy of measurements and compensate for errors caused by dynamic factors in difficult flight conditions, it is advisable to use software correction factors based on flight data (speed, angle of inclination, vibrations, etc.).

In combination with technical solutions for stabilization and protection of devices, the software methods provide a comprehensive approach to improve measurement accuracy, readout stability and data transmission.

Results and discussion

As a model for demonstration of implementation of the presented modifications and creation of prototype of instrument complex in the part related to system of remote control of instruments, reading and transmission of data of measurements, the authors have chosen the measuring device "Meteoskop-M". This instrument is designed to measure microclimate parameters such as temperature, humidity, atmospheric pressure and air flow velocity. However, according to the provisions of GOST 17.2.4.07-90 "Atmosphere. Methods for determining the pressure and temperature of gas-dusting streams from stationary sources of pollution", GOST 17.2.4.06-90 "Protection of nature. Atmosphere. Methods for determining the speed and flow of gas-dust streams emanating from stationary sources of pollution"[2], as well as GOST 17.2.4.07-90 "Protection of nature. Atmosphere. Methods for determining the pressure and temperature of gas-dusting streams from stationary sources of pollution"[3] shall be allowed to use measuring means similar to those given in the document, but with mandatory compliance with the conditions: the selected measuring devices must have similar metrological characteristics. Below is an analysis (Table 1) of the metrological characteristics when measuring the temperature and velocity of the gaseous air flow with the TL-1 thermometer, a Pito tube and the device "Meteoskop-M".

Table 1. **Metrological characteristics of different instruments for measuring temperatures and velocity of gas-air flow**

Measuring instrument	'Meteoskop-M' with sensor probe	Pito tube	TL-2	TL-3
Temperature, °C and error	−40…+85 ± 0,2	–	0…100 ± 1	0…200 ± 2
Gas-air flow velocity, m/s and error	0,1…1 m/s ± (0,05+0,05V) 1…20 m/s ± (0,1+0,05V) where *V* is the value of measured velocity, m/s	Pito (version B) 2…30 ± 3 Pito cylindrical (version B) 4…30 ± 5 Pito (P version) 2…60 ± 3	–	–

Source: compiled by S.V. Simanovich, I.I. Gavrilin.

Temperature and velocity measurements are critical for analytical emissions measurements, where the main task is not just to record air flow parameters but

[2] GOST 17.2.4.06-90. Atmosphere. Methods for determining the pressure and temperature of gas-dusting streams from stationary sources of pollution. *Electronic database of legal and regulatory technical documents*. Available from: https://docs.cntd.ru/document/1200007367?ysclid=mb9pqwd3dx987852665 (accessed: 06.01.2025).

[3] GOST 17.2.4.07-90. Protection of nature. Atmosphere. Methods for determining the speed and flow of gas-dust streams emanating from stationary sources of pollution. *Electronic database of legal and regulatory technical documents*. Available from: https://docs.cntd.ru/document/1200007365 (accessed: 06.01.2025).

to take them into account in the calculation of pollutant concentrations. These characteristics of the gaseous air flow influence the processes of dispersion of pollutants, which must be considered in modeling and forecasting the environmental situation.

During the flight of UAV with a payload, the structure of the carrier platform and its attached equipment are subjected to constant vibration. Vibration effects are caused by the operation of engines, rotation of propellers in different modes and resonance phenomena of frame, and also, to a lesser extent, by external factors – turbulence and wind gusts.

According to a number of studies, it has been established that the vibrations occurring on the frame, in the places where the suspensions are fixed and, accordingly, on the housings installed in the suspensions of multicopter equipment of different configurations, cover a wide range of frequencies – from tens to hundreds of hertz, a the resulting resonance oscillations are between 86 and 673 Hz [12]. In particular, the work of specialists who analyzed the spectrum of magnetic noise recorded during the take-off of an UAV, were detected expressed low-frequency components. Such spectral changes are an indirect indicator of vibrational activity, even in cases where the direct measurement of accelerations has not been carried out [13].

Further study of vibration effects on the multicopter load-bearing platform, conducted on specially designed stands in industrial conditions, showed that the magnitude of the vibrational velocity, vibrational acceleration and the resulting vibration displacement are proportional to the thrust and rotation modes of the air propellers, maximized at high engine speeds. It has been experimentally established that even at the maximum operating modes of multicopter engines, the linear values of vibration displacement of its carrier platform do not exceed tenths of a millimeter [14].

In turn, in accordance with the laws of mechanics and the principles of vibration protection theory, the magnitude of vibration movements affecting the base (carrier platform) are multiplied (sometimes completely reduced) for equipment placed on a mobile two (three) axial suspension to this platform, especially – if there are damping attachments [15].

It should be noted that the above-mentioned studies aimed to evaluate the effects of vibration on the frame of multicopters and the body of equipment directly placed on them. In case of the use of instruments for measurement of aerodynamic characteristics of the gaseous air flow and concentration of pollutants in it, the effect of vibrations on the working unit of the instrument – carried sensor, probe should be considered. This requirement, together with the available experimental data, has been taken into account in the simulation of vibration conditions on the working device, however, in this experiment the intensity of vibration was estimated in dBA, which reflects the logarithmic magnitude of vibrational acceleration along the three axes.

Two stands were assembled to simulate the vibration effects on the working part of the measuring instrument mounted on the suspension in UAV flight conditions (Figure 1).

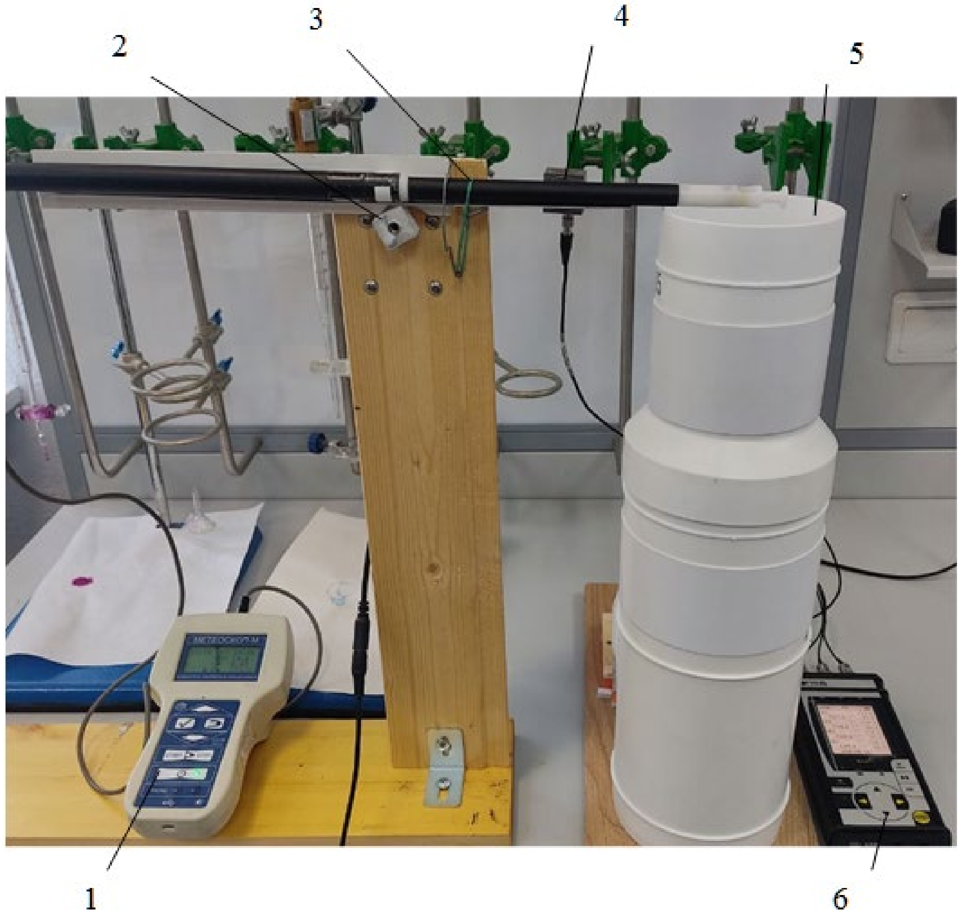

Figure 1. Bench for simulating the behavior of the measuring instrument in the UAV suspension and a point source of air pollution:
1 – "Meteoskop-M" control unit; *2* – motor with a reducer and a square protrusion, to create periodic mechanical impacts on the platform; *3* – platform with a sensorimetric probe (the probe is fixed in such a way as to avoid turning under the influence of vibration; located in the geometric center of the orifice); *4* – accelerometer mounted on the probe and connected to the vibrometer; *5* – simulation of a point source of pollution – a 95 mm diameter pipe with a thrust inducer; *6* – vibrometer "Ecofizika-110V"
Source: compiled by S.V. Simanovich, I.I. Gavrilin.

The experiment consisted of two stages.

1. Measurement of control values without vibrations to determine the background values of the gas flow rate.

2. Impact of vibrations with different amplitude and frequency on the platform with the device's probe attached to it.

The modes of operation of the cam mechanism were gradually set: 1 r/s (low frequency); 1.5 r/s (average frequency); 2 r/s (high frequency).

The amplitude of the platform displacement with the device's clamp fixed on it varied: 0, 0.5 and 1 mm.

For each combination of parameters, the following were recorded: vibration acceleration (dBA), measured air velocity (m/s).

Control measurements without vibrations showed that the air speed in the air duct is 0.48 m/s, and in the environment (without pressure) – 0.07 m/s. Below are the results of the experiment (Table 2).

The experiment confirmed the influence of vibrations on the accuracy of air flow velocity measurements by the device "Meteoskop-M" under conditions close to operation on the suspension of an aircraft. Although the experiment used a logarithmic intensity estimation (in dBA) without frequency analysis, the results confirm the relationship between the level of vibration exposure and data stability. Thus, vibrations should be considered as a significant factor in the operation of devices with removable working elements on the UAV platform.

Table 2. **Summary table of experimental results**

Motor speed (r/s)	Vibration acceleration (dBA, three axes)	Measurement result
Amplitude 0 mm		
1.0	123.5; 120.3; 126.7	0.48
1.5	135.6; 126.3; 139.8	0.48
2.0	134.7; 121.1; 141.8	0.47
Amplitude 0.5 mm		
1.0	121.6; 118.2; 128.2	0.48
1.5	131.8; 136.0; 138.5	0.48
2.0	127.9; 134.6; 138.9	0.49
Amplitude 1 mm		
1.0	121.3; 125.9; 126.2	0.48
1.5	134.4; 135.1; 141.9	0.45
2.0	127.9; 134.6; 138.9	0.43

Source: compiled by S.V. Simanovich and I.I. Gavrilin.

At small amplitudes (0–0.5 mm) the vibrations did not have a significant effect on the measurement results – the flow rate remained stable (0.48–0.49 m/s).

When increasing the amplitude to 1 mm, a systematic decrease in flow speed to 0.43 m/s at 2 o/s is recorded, which may be related to the destabilization of the position of the probe relative to the air flow.

The highest vibrations (up to 137 dBA) are recorded at 1.5 r/s, indicating possible resonance effects in the design.

The data obtained confirm the need for mechanical stabilization of the suspension with the device and its sensor probe, as well as software processing of results to compensate for vibration effects. Additionally, it should be noted that the vibrations were transmitted to the measurement unit "Meteoskop-M" itself, but their influence on the accuracy of measurements was taken into account as a secondary factor.

– Therefore, a comprehensive approach is required to ensure the accuracy of measurements when using the instrument on unmanned platforms, including:

– mechanical stabilization (damping elements in the suspension structure);

– automated measurement correction (data filtering and use of correction coefficients);

– dedicated remote control interface (Figure 2), providing real-time data reading and transmission.

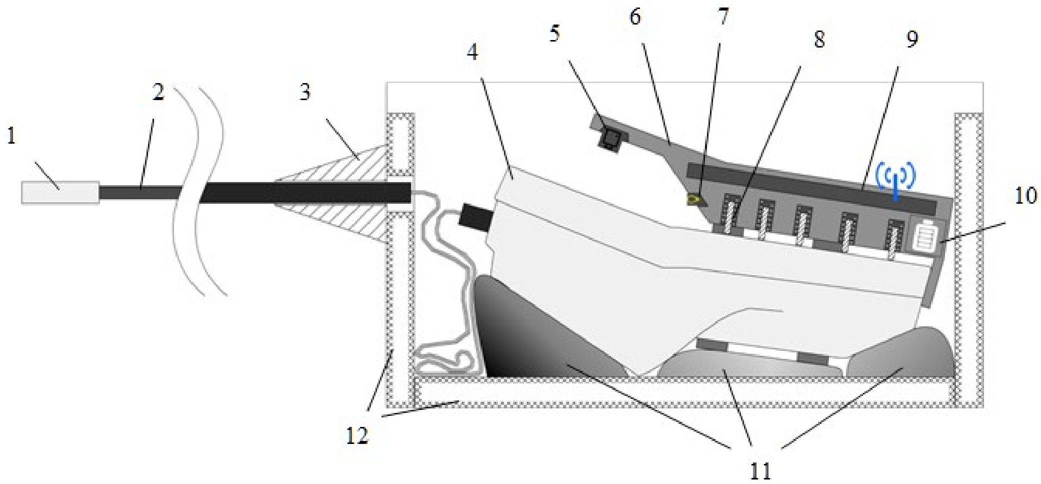

Figure 2. Configuration and placement of “Meteoskop-M” in the UAV hanger:
1 – tip of the sensor probe with sensors of temperature, humidity, air velocity and atmospheric pressure; *2* – sensor probe connected to the device; *3* – fixing probe fitting with a damping layer; *4* – “Meteoskop-M” control unit; *5* – camera directed to the device display; *6* – lining housing; *7* – light bulb for illuminating the instrument display; *8* – solenoids located opposite the instrument controls; *9* – board with antenna for data transmission; *10* – independent power supply of the lining housing; *11* – damping pads under the instrument; *12* – inner lining of the suspension body made of damping material.
Source: compiled by S.V. Simanovich and I.I. Gavrilin.

Using these solutions in combination will significantly reduce the impact of vibrations and other external factors on measurement results, ensuring their stability and accuracy in real flight conditions.

Conclusion

The results of the study confirm that it is possible to use measuring instruments in UAV suspensions in two main ways: by adapting existing instruments through technical and software methods, or by creating new measurement means, specifically designed for use on the UAV platform in flight conditions.

The adaptation of mass-produced devices gives economic and logistical advantages, as it uses certified devices already tested by practice. However, the experiment has shown that the vibration loads during flight have a negative effect on the accuracy of measurements, especially when the amplitude of the oscillations is increased. The technical modifications presented in the work and the software processing options proposed allow to minimize the influence of vibrations, increase the accuracy of measurements and ensure the correct functioning of the instruments in the suspension of the UAV.

The proposed approach is universal, as it uses the possibility of integrating the UAV with traditional means of environmental control, which, according to the experts, allows to complement each other data and ensure the ability to compare air quality indicators at different heights [16], and flexible because it allows to adapt different types of measuring instruments for environmental monitoring tasks related to the inventory of industrial facilities.

The drawbacks of this approach are only minor costs for additional equipment, resulting in a permissible increase in the mass of the complex and an increase in the energy consumption of the system, the need for continuous monitoring and updating of corrective data. However, this approach already allows the integration of UAVs into the environmental monitoring system, ensuring objective data collection and preventing possible pollution.

It is important to note that in order to ensure the reliability and stability of the results under the conditions of a particular platform and task, the adaptation of the instruments must be accompanied by field tests taking into account the characteristics of the frame, suspension, propulsion system and flight dynamics, in turn, will allow adjusting the influence of external factors and improve the accuracy of results.

In the future, the experience gained will serve as a basis for using another approach – the development and creation of specialized remote-controlled instruments, constructively integrated with the carrier platform of UAV for operation in flight. Due to the optimal design taking into account all the characteristics of operating conditions, organic articulation of the UAV transport platform and measuring instruments, the new complex will certainly be more efficient and functional. However, at present it is not feasible to introduce this approach into the practice of environmental monitoring because of its shortcomings: high development and industrial production costs, high material cost requirements, a series of tests and certifications, which significantly increases the time to manufacture on an industrial scale and put into operation.

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