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The Concept of a Collection System for Gas Mixture from the Interior of Chimney Openings for Unmanned Flying Systems

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ABSTRACT
Today, one of the most topical issues related to the quality and safety of life on Earth is the monitoring of air quality in terms of its pollution that is harmful to human health and life. The activities undertaken as part of monitoring carried out include, among others, analysis of the composition of exhaust fumes from emission sources, such as households and industrial entities, in terms of the presence therein of potentially hazardous substances, indirectly in order to detect violations of the applicable environmental standards. In order to conduct this type of analysis, unmanned aerial systems are commonly used, which allow sampling in the immediate vicinity of the emission source. However, the currently functioning solutions do not allow for exhaust fume sampling in a way that allows a mixture for testing to be taken directly from an emission source. This leads to questioning of the reliability of the conducted research, as it is uncertain in terms of the origin of the tested mixture, indicating that the test takes place not at the source of the emission, but in its surroundings. This study proposes a technical solution to sample exhaust fumes directly from the emission source - from the interior of chimney openings.

Keywords: drone, UAV, air pollution, quality, environment, smog, probe, chimney.

INTRODUCTION

Today, one of the most topical issues related to the quality and safety of life on Earth is the monitoring of air quality in terms of its pollution that is harmful to human health and life. Air pollution can lead to numerous diseases and increase the number of premature deaths. The main health threats related to air pollution include, inter alia, cancerous diseases of the respiratory system and the bloodstream, which may lead to a shortening of life [1, 2].

Today, air quality monitoring is not an issue that is only a scientific cognitive analysis, but functions in the practical, everyday short- and long-term needs of societies. It is worth mentioning here that, among others, in Directive 2008/50/EC of The European Parliament and of The Council of 21 May 2008 on ambient air quality and cleaner air for Europe [3], the European Union clearly expressed the need to monitor air quality for substances that may threaten human and life and health.

In recent years, air quality monitoring technologies have undergone significant development, which is also indirectly related to the development of unmanned flying systems technology. It is worth noting that the aforementioned Directive of the European Union published in 2008 deals mainly with ground-based measuring stations, while the possibility of using unmanned systems for this purpose is considered only at a later date [4]. Currently, the use of unmanned aerial systems for local measurements of air quality and composition is already a common phenomenon [5÷7], used both in scientific applications and by public administration, including, inter alia, to penalise violations related to the emission of harmful substances by industrial entities and households.

The sources of air pollution include the products of combustion of wood and solid fuels, and - in particular - waste, the combustion of which causes emissions that have particularly dangerous consequences for health [8]. Therefore, apart from area-based air quality monitoring, it is also

important to monitor selected sites of exhaust fumes. The confirmation of this thesis can be found in the gradual, continually progressing development of unmanned measurement systems, which were initially designed as fixed-wings aircraft, and over time took the form of multi-rotor craft capable of making point measurements in selected places. It should be noted that this possibility was created by the parallel development of unmanned systems in this respect.

Limitations of the application of currently functioning solutions

Currently, the most popular system for monitoring and analysing exhaust fumes from, for example, industrial or domestic chimneys is an unmanned aerial system equipped with sensors for real-time analysis or a sampling mechanism for later analysis, and a longitudinally extended probe for exhaust fumes (air), which reduces the need for the UAV to enter into the tested stream. An example of this type of construction is shown in Figure 1.

The fact that the solution presented above is used as the most common one is confirmed by a market review of unmanned aerial systems for air quality analysis. Apart from the DR1000 Flying Laboratory design shown in Figure 1, a similar solution is available in, among others, the following constructions: DR2000 [10], United Systems SOWA [11], SoftBlue AirDrone [12], and Pelixar AAMS [13]. Among the proposals of unmanned aerial vehicles for air composition measurements available on the market, it is currently impossible to find any other type of solutions, in particular - a solution that allows taking an air sample directly from an emission source.

Fig. 1. Commonly used unmanned air or exhaust fume composition testing system, source: [9]

Samples taken by an unmanned aerial vehicle of the above type may come from the zone immediately close to the emission source, but are not taken directly from the source, e.g. from the interior of the chimney. As a result, the conducted analysis is burdened with a potential error in the influx of air masses from the surroundings, which may interfere with the accuracy of the assessment of the composition of the tested mixture. Moreover, an attempt to insert a rigid probe into a chimney opening may entail the risk of disturbing the stabilisation of the UAV by contact with the elements of the chimney, ultimately leading to permanent damage to the system.

The difficulties presented above were diagnosed based on the actual needs reported by producers and users of unmanned air composition analysis systems. According to the information presented by them, in practical application it is important to be able to clearly define the origin of the analysed mixture. In the case of the solution presented above, the entities monitoring the composition of the emitted exhaust fumes encounter the questioning of the presented results of the analyses, the authors of which raise the possibility of the introduction of harmful substances along with ambient air currents.

METHODOLOGY

Research problem: the currently functioning technical solutions do not allow for the sampling of tested exhaust fumes directly from an emission source. Due to the above, in the face of modern research techniques, there is uncertainty about the actual origin of the mixture being tested. The main technical limitation of the currently functioning constructions is the collection of exhaust fume samples through a longitudinal, rigid sampling probe, the insertion of which into the interior of the chimney opening is not possible in a way that guarantees the safety and efficiency of the operation.

Hypothesis: the solution to the above problem can be achieved by taking a sample of the exhaust fumes directly from the emission source. The solution requires the development of technical improvements that will allow sampling directly from the emission source. A solution of this kind can be developed as an extension of the currently functioning exhaust fume sampling systems.

Research methods: in order to develop a solution aimed at taking a sample directly from an emission source, considerations were made regarding possible solutions and the effectiveness of the selected solution was checked using an experimental method under real conditions. SWOT analysis was adopted as the criterion for the preliminary assessment of possible solutions, seeking the solution with the most favourable ratio of positive to negative features. After selecting the solution, a demonstrator was developed and flight tests were performed to confirm its effectiveness in real conditions.

Considerations and evaluation of possible constructions

In the course of searching for a solution aimed at sampling the mixture in a chimney, the following solutions were considered: inserting an unmanned system into the chimney opening, replacing the rigid sampling probe with a manipulator with a flexible hose, developing a fishing-rod inspired boom for inserting a flexible hose into a chimney opening, and developing a flexible element extending a rigid test probe, inserted into a chimney opening. The SWOT analysis of individual solutions is presented in the tables below.

Detailed description of the chosen solution

After carrying out the above considerations, a decision was made to choose the concept of a solution characterised by the most favourable ratio of positive features to negative features. It was decided to develop a flexible element for extending the measuring probe used in conventional exhaust

Table 1. SWOT analysis of the insertion of a UAV into a chimney

The insertion of a UAV into the chimney	
Strengths	**Weaknesses**
no need to design additional elements	no possibility of insertion into the chimney in the vast majority of cases due to the dimensions of the UAV
Opportunities	**Threats**
not found	risk of losing the UAV due to the possibility of collision with the chimney structure
	inability to make a sufficient miniaturisation of the system in the light of currently available solutions
	risk of failure due to contact with potentially dangerous exhaust fumes

Table 2. SWOT analysis of a manipulator with a flexible hose

Manipulator with flexible hose	
Strengths	**Weaknesses**
sampling from any chimney expected	complicated control procedure expected
	significant number of control elements - servos
	high degree of complexity of the structure
Opportunities	**Threats**
the possibility of adapting the shape of the probe to the needs of a specific chimney structure	the risk of disturbing flight stability due to the contact of the rigid manipulator with the chimney structure
	high risk of failure due to the large number of components

Table 3. SWOT analysis of a boom inspired by a fishing rod

Boom inspired by a fishing rod	
Strengths	**Weaknesses**
sampling from any chimney expected	high degree of complexity of the structure
the insertion of a flexible hose to the chimney reduces the risk of disturbing flight stability	
Opportunities	**Threats**
not found	the hose cannot be disconnected in case of becoming jammed in the chimney

Table 4. SWOT analysis of the flexible probe extension element

Flexible probe extension element	
Strengths	**Weaknesses**
sampling from any chimney expected	the need to develop a sealed mechanism guiding the flexible hose
the insertion of a flexible hose to the chimney reduces the risk of disturbing flight stability	
Opportunities	**Threats**
possibility of disconnecting the hose in case of becoming jammed in the chimney	not found

fume composition testing systems. The solution is to place a flexible hose with a larger diameter on the probe, which moves along it, eventually to be driven by a mechanism sealed with lubricant. In order to make a preliminary assessment of the solution, the demonstrator presented in Figure 2 was developed. The Hexakopter X01 multi-rotor unmanned aerial vehicle system equipped with a conventional measurement system for testing the composition of exhaust fume mixture was used as the carrier platform.

As can be seen in the above photograph, the developed solution is based on a traditional measurement system with a rigid, longitudinally guided probe, and is a development of it. In the developed demonstrator, the assembly of a drive mechanism was abandoned, and the hose was fed out manually to confirm the usefulness of the solution.

The possibility of taking a sample of the mixture from the interior of a chimney opening was ensured by extending an elastic element - a hose, which during the extension under the influence of its own weight obtains a shape that allows for insertion. Depending on the shape of the opening, it is possible to differentially load the end of the flexible hose in order to obtain the appropriate insertion profile. Adaptation to the size of the tested chimney can be done by selecting the length of the probe indirectly affecting the length of the sampling hose. In the event of the probe becoming jammed in the chimney opening, it is possible to completely slide the rubber hose off the rigid probe to allow the UAV to free itself and return to the launch site.

Experiment - flight tests

In order to confirm the effectiveness of the proposed concept, it was decided to conduct flight tests in which the demonstrator presented above was used. The design of the probe with a flexible hose made it possible to collect a sample from the interior of various chimney openings. Figure 3 shows the demonstrator during suspended static preliminary tests, while Figure 4 and Figure 5 shows the demonstrator in flight during sampling from various types of chimney openings.

The tests were performed for various types of chimney openings commonly used in households. During all the tests performed, the mixture was sampled efficiently. Within the framework of the performed trials, no cases of ineffectiveness were found for the proposed solution.

Fig. 2. Demonstrator of the measuring probe for testing of emission source exhaust fume composition

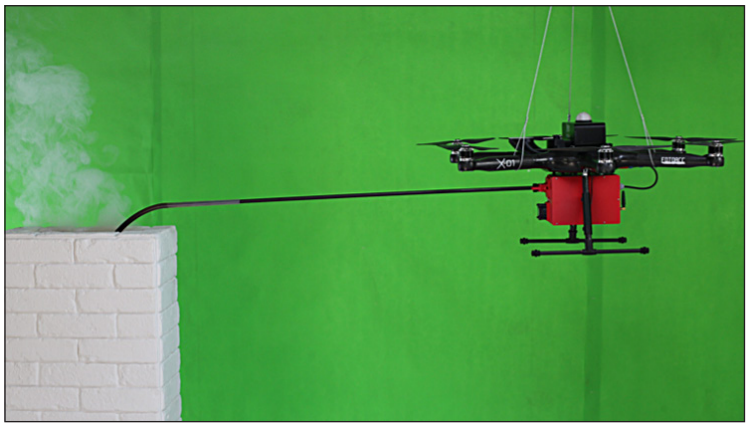

Figure 3. Demonstrator during a static test

Fig. 4. Demonstrator taking a sample from a chimney opening 1

Fig. 5. Demonstrator taking a sample from a chimney opening 2

CONCLUSIONS

As part of the presented work, considerations were made on the possibility of collecting a sample of a gas mixture from the interior of chimney openings by unmanned aerial vehicles. Based on the considerations, the most promising concept was selected, which was developed in the form of a demonstrator with limited functionality, devoid of an automated drive mechanism. The conducted flight tests confirmed the effectiveness of the selected concept by way of experimentation in real conditions in all the cases undertaken.

In the context of the considerations presented above, the proposed solution is characterised by a number of advantages. First of all, the solution meets the fundamental requirement of making it possible to sample the gas mixture

from the interior of chimney openings. In addition, the design also ensures relatively high safety of operations due to the fact that the contact of the flexible hose with the elements of the chimney carries a relatively low risk of loss of the unmanned aerial vehicle's flight stabilisation. The developed solution enables the disconnection of a part of the probe in the event of it becoming jammed in a chimney opening. Moreover, the proposed solution consists of a relatively small number of elements, without significantly affecting the weight of the system.

Due to the satisfactory results of the conducted flight tests, a decision was made to carry out further work on the presented concept. It is planned to develop a sealed remotely controlled drive mechanism. After developing and checking the operation of the drive mechanism, it is planned to conduct comparative tests to assess the impact of the sampling point (from the chimney or from the surroundings) on the results of the analyses of exhaust fume composition.

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