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UAV-SYSTEM FOR REMOTE ASSISTED MEDICAL DIAGNOSTICS AND PULMONOLOGICAL MONITORING OF POTENTIALLY INFECTED WITH COVID-19 PATIENTS "TREMBITA-CORONA UAV NAU"

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Abstract

UAV-supported instrumental diagnostics system for remote acoustic investigation and monitoring of lungs for managing patients within the framework of telemedicine has been developed. The system includes a user set of control and measuring equipment and a UAV carrier for delivery and organization of the patient testing procedure.

Keywords: pulmonary monitoring, acoustic methods, device, telemedicine, design, mass production

1. State of the art and problem statement

Analysis of the incidence of COVID-19 among various population groups in accordance with the World Health Organization (WHO) data shows that the greatest risk of infection is associated with health and service care workers [1]. Thus, an analysis of official data [2] for Ukraine shows that the percentage incidence rate of COVID-19 for medical workers during the initial period of the fight against the pandemic exceeds the percentage incidence rate for other population groups by more than eighteen times.

The only way to reduce the incidence of these social groups is to significantly reduce contacts with sick or potentially infected people, which is virtually impossible for medical workers, since it is they who diagnose the COVID-19 illness at the first stage of medical care.

Most often, contamination, as shown by an expert analysis carried out among medical workers who became ill with COVID-19, occurs during the initial examination, when the question of the patient's illness with COVID-19 has not yet been resolved [3].

Known approaches to solving this problem, such as the use at the stage of the initial analysis of the patient's condition of expensive stationary hardware equipment in medical institutions, namely, ultrasound, X-ray devices, computer tomography devices [4], in order to avoid or reduce the duration of contact directly between the doctor and the patient, not only do not provide full protection and distancing for the attending physician, but are also associated with a significant additional risk of the spread of the virus during transportation of the patient to a medical institution, with the risk of a negative impact of such transportation on the patient's course of illness, and most importantly, they cannot ensure the massiveness of the routine procedure, not only in developing countries due to the lack of such hardware systems in sufficient quantity in many cases, but also in countries with a high level of medical provision.

Thus, within the framework of the first stage in the provision of medical care or in the course of further management of the patient, the **task** is to provide the safest possible for the doctor, service personnel and patient, as well as others, obtaining objective information about the patient's condition, sufficient for making a diagnosis, as well as prompt decision acceptance about the type of further treatment or the need of sending the patient to a medical institution for applying additional diagnostic methods.

A comprehensive **solution** to the described problem is possible by creating a system that allows self-diagnostic of a patient, who is potentially infected with COVID-19, using modern control and measuring equipment with remote contactless monitoring of the patient by a medical worker, as well as developing a mechanism for prompt delivery of this equipment to the patient using specialized Unmanned Aerial Vehicles (UAVs) as a part of the specified diagnostic and monitoring system.

The **purpose** of this article was, therefore, the forming of a principal concept of the UAV-system for remote assisted medical diagnostics and pulmonological monitoring of the condition of patients potentially infected with COVID-19, which was named "Trembita-Corona UAV NAU".

2. Formation of a concept of a UAV-supported telemedical instrumental self-diagnostics system

The first problem that needs to be addressed in order to reduce the incidence of COVID-19 among medical workers and also especially among service personnel, is the delivery of appropriate control and measuring equipment to a patient who is potentially sick with COVID-19. It is at the time of its transfer to a potentially ill patient that the attendants become infected, which significantly increases the risks of further spread of the disease, since the attendants are in contact in accordance with their functional duties with a large number of people who can be potentially infected.

A state of the art solution to this problem is possible with the use of UAVs for the delivery of the corresponding control and measuring medical equipment to users. This approach has a number of advantages, which in addition to ensuring contactless transfer of instrumentation and further remote diagnostics, also include the potential for mass usage, for organization of prompt control and of mass routine regular testing. In particular, this is important for monitoring and controlling patients with mild symptoms who are on self-isolation or home treatment, in order to avoid delays in diagnosing the patient's transition to the acute stage of the disease.

In addition, UAV delivery of user equipment to patients for remote diagnostics opens up a completely new direction of development of the telemedicine concept. It should be noted that the WHO pays highly increased attention to development of telemedicine in connection with the COVID-19 pandemic [5].

However, this approach imposes certain restrictions on the mass characteristics of medical equipment.

Creation of such equipment provides, in accordance with the above-described formulation of the research problem, the development of a methodology for remotely corrected by a doctor instrumental self-diagnostic of the patient. In some cases, such a diagnostic or routine monitoring can be carried out with the help of an assistant, who is in most cases a relative or a person who are already being in close contact with the tested potentially sick person.

Modern computer digital technologies make it possible to create such operational control systems, which ensures the receipt of objective instrumentally measured data on the patient's condition, when performing self-diagnostic or self-diagnostic assisted by an untrained assistant.

Methods for determining the illness of COVID- 19, traditionally used for diagnostic, such as measuring temperature, assessing the patient's well-being, taking anamnesis, do not provide sufficient diagnostic information to justify an accurate diagnosis.

The seeming promise of such medical methods as polymerase chain reaction and immunological tests requires the delivery of samples to the laboratory, a time delay for laboratory studies, and besides, obtaining biological material for analysis is a complex invasive procedure that is almost impossible to perform independently or with the help of an untrained assistant at a sufficiently high quality level. Similar problems arise with other control methods.

The optimal method should possess the following characteristics: prompt testing procedure, unambiguity, maximum information content, suitability for conducting monitoring independently or with the help of an untrained assistant, ability to be remotely controlled by the doctor, ability for the

measured data to be analyzed the doctor in real time.

Based on this, the acoustic diagnostic method is promising and currently underestimated due to the lack of practically applicable systems for remote data acquisition.

In this case, two directions of acoustic diagnostics can be distinguished, namely, according to the peculiarities of noise generated by the affected areas of the lungs, and the most efficient method for assessing the sound of a patient's cough.

At this stage, the second method, despite its apparent clarity, has not received appropriate development from the medical staff. In most cases, medical professionals and specialists assess the cough during COVID-19 disease as dry as opposed to wet and agree on its non-specificity [6], although the amount of information that acoustic data carry when coughing is much greater.

The prospects of the method of acoustic diagnostics of lungs for COVID-19 cases are shown in works [7, 8]. Attention should be paid to the possibility of early diagnosis of lesions at COVID-19 in lungs in areas hidden by bone tissues, incl. the patient's ribs. Such the problem cannot be solved by ordinary auscultation with usage of a mechanical or electronic phonendoscope by a medical worker, even during a normal direct contact investigation. But the proposed monitoring devices of the "Trembita-Corona UAV NAU" type provide this opportunity both in contact and in remote modes.

This approach to remote monitoring required development of a method for conducting acoustic studies that could be carried out directly by the patient himself or by untrained personnel using a formalized procedure under the remote control of a doctor.

Fig. 1, a and b show the proposed division of the patient's chest area into diagnosted and monitored zones that are easily amenable to remote correction by trained medical personnel.

Characteristic zones of the patient's right and left lungs are considered, which in formalized control programs are designated by the first Latin letters R and L. The first two zones, as shown in the fig. 1, a, form the regions R1 and R2, and also L1 and L2, respectively, which are used mainly for recording parameters the patient’s cough. Accordingly, the right and left lungs in this case are divided into six main and additional zones.

Inside each zone, there is a system for acquiring acoustic information, containing four receivers placed in a cross-shaped pattern. The optimality of the cruciform arrangement of receivers in investigated zones is shown in [9].

Fig. 1, c and d show proposed zones of acoustic control of the patient's lungs in their accordance with the numbered in the figure lung segments according to A. Maksimenkov, adopted in classical medicine. The importance of taking into account this correspondence is associated with the fact that, in the general case, the structural and morphological subdivision of the lung tissue into segments contributes to the initial localization of infectious processes within individual segments.

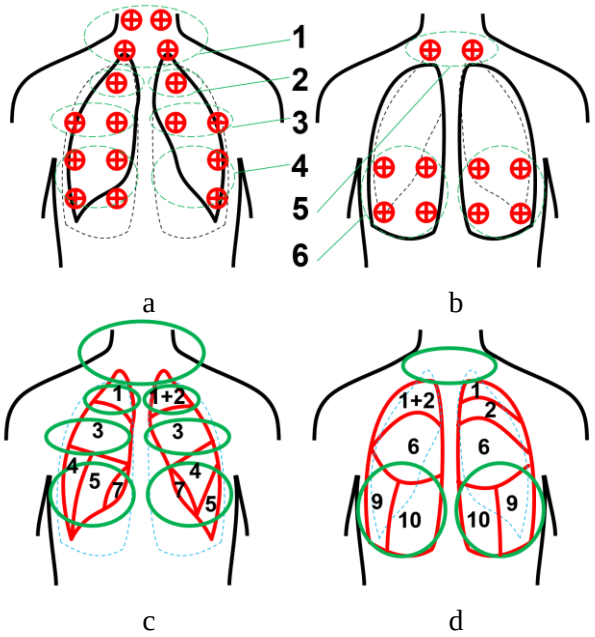


Fig. 1. Proposed zones for acoustic monitoring of patient lungs using the "Trembita-Corona UAV NAU" remote diagnostic and monitoring UAV system (a and b – front and back views, respectively), and the correspondence of the allocated zones to morphological lung segments (c and d – front and back views, respectively)

This means that even in case of an occuring generalization of the inflammatory process into large areas, the features of the course of the disease in different segments differ from each other. An additional factor that determines the importance of the localization of the inflammatory process during diagnostic and monitoring of the patient's condition is that during treatment with physiotherapeutic methods it becomes possible to influence individual segments or groups of segments of the lung.

This approach made it possible to propose locating of the acoustic signal receivers on a special vest. This approach is especially relevant for patients

in pediatrics, since it makes it possible to quickly gain the required acoustic information, taking into account the age-related characteristics of patients' behavior.

When using the developed methodology for conducting a diagnostic examination of a patient, it is possible to use sized vests with a rigid arrangement of sensors, or universal models of a measuring vest with clips for precise locating of Acoustic Data Acquisition Points (ADAPs). The first method ensures the efficiency of obtaining the result, but potentially has a lower sensitivity due to the possible unsuccessful coincidence of the ADAPS with peculiarities of the patient's physique. In the latter case, with the help of the patient himself or an untrained assistant, the location of the ADAPS can be corrected by the medical worker remotely.

Separately, it should be noted the possibility of including a linear strip set of ADAPS with an adjustable position of points in the set of the diagnostic system delivered to the patient, which allows detailed scanning of individual areas of the chest if necessary.

3. Features of circuit solutions for instrumentation of acoustic monitoring of lungs

Implementation of the concept of location of acoustic signal receivers using elaborated measuring vests, required development of a specialized controller for processing acoustic signals. Calculations and experience have shown that the required sampling frequency of each of the channels is at the level of 1 MHz, despite the fact that recorded frequencies lie in the range from 10 Hz to 20 kHz, i.e. the usual approach of at least two-fold excess of the sampling frequency above the value of the registered one should be significantly exceeded.

All channels for transmitting audio information are well coded and can be compressed and transmitted by one channel for transmitting video information.

This approach is due to the peculiarities of the mathematical processing of acoustic signals from each of the receivers and the refined positioning of the lesion sites in the lungs with minimal acoustic bases.

The second feature of the developed specialized microcontroller is the simultaneous capture and sampling of signals from all acoustic receivers. The central microcontroller issues a command to all analog-to-digital converters to capture and store data at the current time. After capturing, all information from all channels is stored in the controller's random access memory, and subsequently sequentially transmitted by a separate communication controller for further processing and analysis.

In some cases, if only operational prompt control by a doctor is performed without recording acoustic information and without refined positioning of the signal source by the computer system, then it is possible to significantly simplify the circuit design of this element of the device.

In this case, it is possible to recommend monitoring separately in each of the allocated zones with a sampling rate from 100 to 200 kHz.

When carrying out a prompt express control, it is possible to reduce the sampling frequency of the signal to 64 or 48 kHz with the transmission of this signal through communication lines, including using mobile networks, almost in real time.

However, this approach, in the case of using a UAV as a carrier and prompt delivery of equipment to a patient, makes it possible to expand the capabilities of the system. Even relatively simple communication and information transmission systems used by UAVs to control their control and movement along a given route with image visualization are multi-channel well-developed communication channels that can be used to transmit medical information, including over coded lines with increased transmission security.

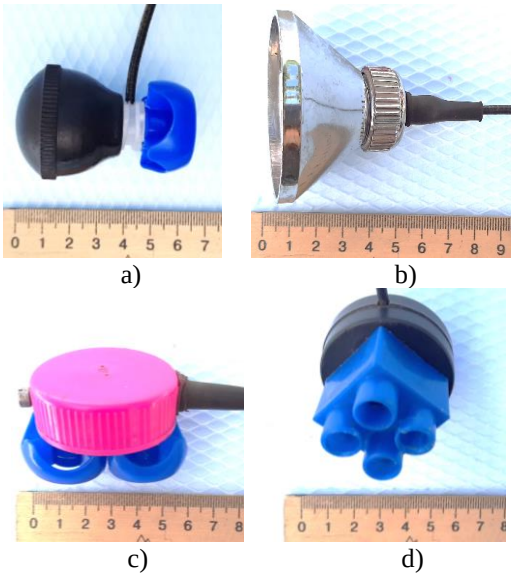
Fig. 2. shows a photograph of an example of using a UAV’s monitoring video camera, which delivered the developed complex of equipment for acoustic monitoring of lungs to a patient for his remote monitoring by medical personnel. In this case, the medical staff tracks the actions of the patient or his assistant during the procedure for monitoring of lung damage with single-point single- or multi-channel or multi-point receivers of acoustic information.

The introduction of special racks and clamps into the design of the UAV body makes it possible to position the UAV in a vertical plane or fix it on the patient's bed so that the UAV's video camera is directed at the areas of the patient's chest, which are remotely controlled by the doctor or the assisting trained operator.

Fig. 2. An example of the use of a monitoring camera of a delivery UAV for remote monitoring of a patient by medical personnel of the "Trembita-Corona UAV NAU" system.

Thus, the UAV carrier is equipped with a flight control system, a video communication system with a medical worker or also with service personnel, specially installed mounts for transporting the instrumentation measuring equipment of the telediagnostics system, as well as an auxiliary system for deploying diagnostic equipment, including, inter alia, supports and tripod mounts.

In Fig. 3, the photographs illustrate one-point pediatric (a), one-point therapeutic (b), two-point (c) and four-point cruciform (d) receivers of acoustic information.



a) b) c) d)

Fig. 3. Receivers of acoustic information as constitutive element of the UAV-system for remote diagnostics and monitoring "Trembita-Corona UAV NAU":
a) – one-point pediatric; b) – one-point therapeutic;
c) – two-point; d) – four-point cruciform

It should be noted that single-point systems for acoustic control of lungs with manual control, in comparison with multi-point ones, are relatively simple in circuit solutions, which allows them to quickly establish their mass production at a minimum cost of the product. That even allows making them a disposable consumable in the long term perspective.

4. Conclusions

Designing a UAV-system for remote acoustic diagnostics and monitoring of the lung condition for managing patients within the framework of telemedicine is shown to be a state-of-the-art important task. The principal operational concept of such the system has been elaborated and the created "Trembita-Corona UAV NAU" system for remote assisted medical diagnostics and pulmonological monitoring of the condition of patients potentially infected with COVID-19 includes a user set of instrumentation measuring equipment and a specialized UAV carrier used to deliver the specified equipment to a patient using remote control systems and video communication. Methods for integrating a UAV as a component of a telemedicine system using its body and electronic devices both for delivery and for organizing a direct procedure for acoustic testing of a patient are shown.

The possibility of quickly setting up of mass production of the developed telediagnostics and telemonitoring system in order to quickly reduce the risk of the spread of COVID-19 in a pandemic is shown.

The system is not certified and further clinical trials are needed.

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БПЛА-система дистанційної асистованої медичної діагностики і пульмонологічного моніторингу стану потенційно заражених COVID-19 пацієнтів "TREMBITA-CORONA UAV NAU"

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Розроблена БПЛА-система дистанційної акустичної діагностики і моніторингу стану легенів для ведення пацієнтів в рамках застосування телемедицини, яка представляє собою користувацький набір контрольно-вимірювального обладнання та БПЛА-носій для доставки і організації процедури тестування пацієнта.

Ключові слова: діагностика легень; акустичні методи; телемедицина; прилад; конструкція; масове виробництво.

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БПЛА-система дистанционной ассистированной медицинской диагностики и пульмонологического мониторинга состояния потенциально зараженных COVID-19 пациентов "TREMBITA-CORONA UAV NAU"

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Разработана БПЛА-система дистанционной акустической диагностики и мониторинга состояния легких для ведения пациентов в рамках применения телемедицины, которая представляет собой пользовательский набор контрольно-измерительного оборудования и БПЛА-носитель для доставки и организации процедуры тестирования пациента.

Ключевые слова: диагностика легких; акустические методы; телемедицина; прибор; конструкция; массовое производство.

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