ENVIRONMENT PROTECTION, CHEMICAL AND BIOTECHNOLOGY

UDC 616-073.75(045)
DOI: 10.18372/2306-1472.82.14612

Volodymyr Isaienko[1]
Volodymyr Kharchenko[2]
Vyacheslav Astanin[3]
Ganna Shchegel[4]
Valentyna Olefir[5]
Oleksii Olefir[6]
Andrii Olefir[7]
Olha Khomych[8]
Volodymyr Khomych[9]

SYSTEM FOR ACOUSTIC DIAGNOSTICS AND SYMPTOMATIC ASSISTANCE TO COVID-19 PATIENTS FOR USE IN EXTREMAL CONDITIONS "TREMBITA-CORONA NAU"

National Aviation University, 1, Lubomyr Husar ave., Kyiv, 03058, Ukraine
E-mails: [1]volodymyr.isaienko@gmail.com, [2]kharch@nau.edu.ua, [3]astanin@nau.edu.ua, [4]ashchegel@nau.edu.ua, [5]inf159vs@gmail.com, [6]oiolefir@ukr.net, [7]andolefir@gmail.com, [8,9]khomychov@gmail.com

Abstract

The possibility of rapid adjustment of mass production of systems for acoustic pulmonary monitoring and symptomatic assistance to those affected by COVID-19 in the most difficult situation of the pandemic is considered.

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

1. Formulation of the problem

Under the difficult conditions of the pandemic of COVID-19, the problem of instrumental and technical support of doctors dealing with issues of diagnostics and symptomatic assistance to patients with coronavirus infection become urgent. Traditionally, acoustic methods of lung condition monitoring, which are the main methods for diagnosing first-line patients, play an important role among the diversity of diagnostic methods. Features of the spread of COVID-19 desease during the pandemic indicate feasibility of creating specialized pandemic systems for acoustic control and symptomatic assistance, which, given their mass production and use, could reach every doctor in the most remote places and help diagnose and treat symptoms of first-line patients before getting them to inpatient treatment complexes, which have sophisticated modern medical equipment.

Specifically to solve these problems, at the National Aviation University and the National Medical University of Ukraine, a system for acoustic pulmonary monitoring and symptomatic assistance to the patients affected with COVID-19 was created under the unifying logo "Trembita-Corona NAU".

2. Analysis of research and publications

Analysis of the literature has shown the widespread use of acoustic methods for controlling the lung disease of patients with coronavirus. At the first line of diagnosis of patients, doctors use conventional phonendoscopes to evaluate patients' lesion condition by hearing [1]. Percussion diagnostic methods are also widespread [2]. However, with these methods of diagnosis, the doctor is at risk through direct contact with the patient. Existing devices for receiving acoustic information via electronic systems are not adapted to the requirements of pandemics, as they require special disinfection to which they are not adapted. There is a huge problem of early diagnosis of lungs by acoustic methods, especially in children in the early stage of the lesion, when the ribs cover the source of the acoustic signal of the affected area [3]. There is no known information regarding the acoustic methods of symptomatic care for COVID-19 infected lungs.

The purpose of this article is to demonstrate the possibility to create, mass produce, and widespread use of systems for monitoring and diagnosis of affected by COVID-19 persons and to provide them symptomatic assistance, including conditions when doctors are restricted to only remote care of patients due to induced by the pandemic compelled transition to telemedicine.

3. Article text

Specially for solving problems of remote diagnosis and symptomatic assistance to COVID-19 patients with acoustic methods, the system "Trembita-Corona NAU" is created, which consists of separate modules that can perform complex and independent tasks of diagnosis, monitoring and symptomatic help. The system consists of four main modules. The Trembita-Corona M module is designed for remote acoustic pulmonary monitoring with a remote acoustic information processing center. The Trembita-Corona BISS module is a more powerful system of acoustic pulmonary monitoring with the possibility of localization of the areas of lesions, including in the areas behind ribs. Module "Trembita-Corona P" is actually an automated complex that has the ability to assess the lungs of patients by percussion in the absence of direct contact of the doctor's fingers with the patient. The "Trembita-Corona AS" module provides symptomatic assistance to patients with pneumonia by influencing the affected areas of the lungs with acoustic vibrations of a certain frequency spectrum, which helps to clear the interalveoli zones from the fluid that accumulates in these areas and is hard to remove with coughing.

Fig. 1. shows the appearance of the acoustic receiver unit and block diagram of the operation of the module "Trembita-Corona M" intended for remote acoustic monitoring of the lungs with a remote processing center of acoustic information.

Fig. 1. The appearance of the acoustic receiver unit and block diagram of the operation of the module "Trembita-Corona M"

The acoustic receiver unit of the Trembita-Corona M module consists of a microphone unit, a pre-amplification and matching unit, and a data transmission unit.

A feature of the microphone assembly with the connection cable is its complete tightness, which allows it to be disinfected in any disinfectant solution at a disinfection temperature of not more than 90°C. Disinfection in alcohol solutions by immersion at any time according to the disinfection protocols is recommended.

The pre-amplification and matching unit and the data transmission unit are located under the physician's protective suit, i.e. in the area conditionally considered as safe from the point of view of possible danger of contamination spread. The data transmission unit digitizes the received signal and transmits it. Data is transmitted to the acoustic data analysis center via Wi-Fi, Blutooth or wireless telephone networks. Once the information is received, the data center processes the information received and transmits it in real time for later use, including the ability to display it on the monitor of the data center. If necessary, the acoustic information processing center transmits in the opposite direction to the data transmission unit, which can be displayed on the monitor screen or in audio form. Feedback promptly provides the operator with the necessary information.

Module "Trembita-Corona BISS", functional diagram of which is shown in Fig. 2, is a more powerful system of acoustic monitoring of the lungs with the ability to locate the areas of lesions, including in the areas behind ribs.

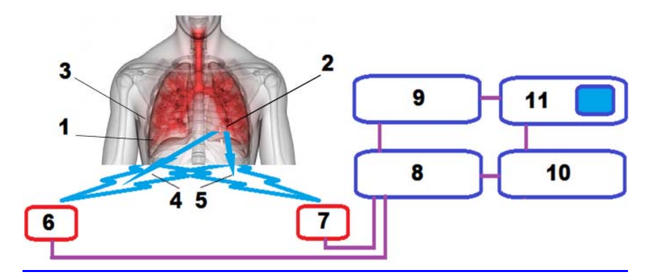

Fig. 2. General outline of the proposed method of acoustic control of the condition and damage to the lungs

The essence of the proposed method of control is recording and analysis of acoustic oscillations using at least two receivers. After processing these signals, we find both the nature and characteristic features of these oscillations, and calculate the direction and position of the source of these oscillations by acoustic triangulation of this signal, which allows to accurately determine the location of the lesion in the lungs. If to carry out measuements in many locations, it is possible to draw an overall picture of the lung condition in real time. A general block diagram of the proposed method of acoustic pulmonary monitoring is shown in Fig. 2.

As shown in the block diagram, during the lungs 1 functioning, in the affected areas 2 of lungs 1 oscillations in the acoustic frequency range are emerging and propagating in the patient’s chest 3. The frequency spectrum of these oscillations depends on the parameters of respiration and the state of the lungs. These oscillations cause further propagating acoustic waves in the air environment and acoustic waves in the body of patients 4 and 5. The most promising is the use for the analysis of acoustic waves in the body 4 and 5, as information about the state of the lungs carried by acoustic waves propagating in the air environment may be interfered with acoustic radiation from other sources.

Acoustic oscillation sensors 6 and 7 perceive these acoustic oscillations 4 and 5 and transmit the corresponding electrical analog signals along the communication lines to the matching unit and the digital-to-analog conversion unit 8. The microprocessor unit of analysis of acoustic signals 9 provides an opportunity to analyze the spectrum and draw conclusions about the state of lungs. Microprocessor positioning unit 10, having analyzed and comparing the arrival time of acoustic oscillations 4 and 5 to the acoustic oscillation sensors 6 and 7 respectively, and applying the received coordinate information to the location coordinate of the lungs and acoustic oscillation sensors 4 and 5, issues to the operational unit 11 calculated position of the source of acoustic vibrations and information regarding the state of the lungs. The location of the acoustic oscillation transducers across the ribs makes it possible to monitor the condition of the lungs in the areas behind ribs over the entire surface of the patient's chest.

Module "Trembita-Corona P" is actually an automated complex that gives the ability to assess the lungs of patients by percussion in the absence of direct contact of the doctor's fingers with the patient.

The essence of the proposed method of control is the loading of the controlled area of contact with variable mechanical loading by means of an indenter, the oscillation frequency of which lies in the audio frequency range, and registering response of this system. When carrying out control measurements at many points, it is possible to draw an overall picture of the lungs state in the contact area.

The conducted mathematical modeling, which theoretically proved the possibility of control, allowed to develop an experimental model of the control device, which consists of two blocks, namely an electromechanical sensor with an indenter and a block of electronic control and indication.

The general view of the electromechanical system of the developed device is shown in Fig. 3. The instrument cover is removed. The electromechanical sensor of the device is mounted on a plastic housing 1, which is a U-shaped profile, the inner part of which is used to position the main elements. In the slot of the housing 1 two housing holder membranes are glued, where the left holder is a housing of displacement sensor 2 of the indenter 3, made in the form of a cylindrical rod with a sharpened end. The core of the indenter is made of instrumental elastic steel. The right holder is also the housing of the electromagnetic oscillation device 4 of the indenter 3. To the membranes of the displacement sensor 2 and the electromagnetic oscillation device 4, indenter 3 is mounted on the sliding hinges 5, the backlash in which is compensated by adjusting screws 6.

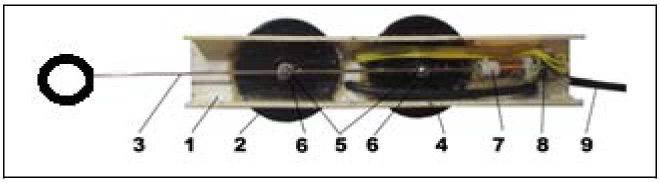

Fig. 3. General view of the electromechanical sensor of the device

In the right side of the housing 1 is a coil spring-electromagnetic loader 7 and the optical system of the position sensor 8 of the indenter 3 with a spherical thimble.

The electromagnetic oscillation device 4 of the indenter 3 is an electric coil with a resistance of 65 Ω, with a copper wire of 0.2 mm thickness which is wound on a U-shaped metal frame made of special transformer steel. The metal U-shaped core is magnetized by a permanent magnet located near the free U-shaped part of the coil such that the diaphragm that defines oscillations of the indenter 3 closes the alternating magnetic field that is generated by the passage of alternating electric current through the coil. The form of alternating current passing through the coil determines the variable form of oscillation of the membrane, which is transmitted to the indenter 3. Thus, by specifying the form of current passing through the coil, we set the frequency and form of oscillations of the indenter.

The displacement sensor 2 is a membrane which oscillates together with the indenter 3 and creates around it acoustic vibrations in a special cavity of the sensor, which are detected by a highly sensitive microphone of the condenser type with the polarization of one of the covers of this condenser microphone.

Thus, the high sensitivity of such the sensor is achieved. This sensor design allows for accurate estimation of the elastic vibrations of the indenter 3.

The spring-electromagnetic loader 7 is an electrical coil that creates a permanent electromagnetic field and, by pushing the end of the indenter 3, which is made of metal, provides a constant load at the end of the indenter 3, pressing it with a fixed load to the area under study. The initial load of the indenter is specified by a micro spring located inside the coil. The original shape of the coil with its relatively large length compared to the diameter of the metal end of the indenter 3 provides electronic control of the current through the coil fixed clamping of the indenter 3 to the area under study. The optical system of the sensor of position 8 of the indenter 3 is an optical system consisting of light and photodiodes, which work to reflect light from the rear mirror end of the indenter 3, and provides electronic control of the current passing through the coil so that the indenter 3 is always in the same position while providing the specified clamping force in the area under study. The positioning accuracy of the indenter is 0.1 mm with an indenter length of 120 mm. This design ensures the constancy of geometric shapes of the oscillating system of the indenter 3 in combination with the loader 4 and the oscillation sensor 2 with an accuracy of 0.1%, which determines the accuracy of the developed device.

The plastic housing 1 of the electromechanical sensor of the device in the folded state is closed by a figured plastic cover, in which holes are made for access to the adjusting screws 6, and the protective figured outlet of the pointed end of the indenter 3. The plastic housing 1 and the figured plastic cover are fixed to each other by the original plastic clamps of the squeeze action. The displacement sensor 2 and the electromagnetic oscillation device 4 are closed by special cylindrical plastic covers that attach to the housings of the threaded membrane holders. The special cylindrical plastic lids have openings through which special copper nuts are contacted, to which the power wires of these devices are connected to the outer parts. This design provides access to the internal parts of the displacement sensor 2 and the electromagnetic oscillation device 4 to adjust them. The multi-stranded shielded wire 9 electromechanical sensor of the device is connected to the electronic control unit and display of the device. To protect the output of the wire from bending on the sensor housing is a cylindrical protrusion.

Module "Trembita-Corona AC" is developed by analogy to systems of reduction of consequences of oxygen poisoning of crew members of military planes after long-term use of oxygen masks. The module function is based on influence on the affected areas of lungs of acoustic vibrations of a certain frequency spectrum, which helps to clear the inter-alveolar zones from the fluid that accumulates in these areas and is hard to remove with coughing. The system is characterized by the fact that the body with the affected lungs itself generates oscillations of the muscles that facilitate the removal of fluid from the lungs, which are recorded by acoustic receivers, and after analyzing them in digital form, the selection of the useful signal and its amplification, are fed by electromagnetic radiators of mechanical oscillations to the area of the lesion zone.

Remote diagnosis and symptomatic care system for COVID-19 patients with acoustic methods of "Trembita-Corona NAU" type was tested on volunteers and showed full functional performance and reliability.

The moral and ethical aspects of the medical use of the systems of remote diagnosis and symptomatic assistance to patients with COVID-19 acoustic methods "Trembita-Corona NAU" type were not considered in this work.

4. Conclusions

The possibility of rapid adjustment of mass production of systems for acoustic monitoring of the lungs condition and symptomatic assistance to those affected by COVID-19 in the most difficult situation of a pandemic is shown.

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

References

[1] Buonsenso D. (2020). COVID-19 outbreak: less stethoscope, more ultrasound / D. Buonsenso, D. Pata, A. Chiaretti // The Lancet Respiratory Medicine. – ISSN 2213-2600, DOI: 10.1016/S2213-2600(20)30120-X. Available at: www.sciencedirect.com/science/article/pii/S221326002030120X.

[2] Thomas P. (2020). Physiotherapy management for COVID-19 in the acute hospital setting: clinical practice recommendations / P. Thomas, C. Baldwin, B. Bissett, I. Boden, R. Gosselink, C. Granger, C. Hodgson, A. Jones, M. Kho, R. Moses, G. Ntoumenopoulos, S. Parry, S. Patman, L. Lee // Journal of Physiotherapy. – ISSN 1836-9553, DOI:10.1016/j.jphys.2020.03.011. Available at: http:// www.sciencedirect.com/ science/ article/ pii/ S183695532030028X.

[3] Rao A. (2018). Acoustic Methods for Pulmonary Diagnosis / A. Rao, E. Huynh, T. J. Royston, A. Kornblith, S. Roy // IEEE Reviews in Biomedical Engineering. – UCSF. — Vol. 12. – pp. 221-239. DOI: 10.1109/ RBME.2018.2874353. Available at: https:// escholarship.org/ uc/ item/ 636268f4).

В.М. Ісаєнко[1], В.П. Харченко[2], В.В. Астанін[3], Г.О. Щегель[4], В.С. Олефір[5], О.І. Олефір[6], А.О. Олефір[7], О.В. Хомич[8], В.М. Хомич[9]

Система акустичного діагностування і симтоматичної допомоги хворим на COVID-19 в екстремальних умовах "Трембіта-Корона НАУ"

Національний авіаційний університет, просп. Любомира Гузара, 1, Київ, Україна, 03058
E-mails: [1]volodymyr.isaienko@gmail.com, [2]kharch@nau.edu.ua, [3]astanin@nau.edu.ua, [4]ashchegel@nau.edu.ua, [5]inf159vs@gmail.com, [6]oiolefir@ukr.net, [7]andolefir@gmail.com, [8,9]khomychov@gmail.com

Показана можливість швидкого налагодження масового виробництва систем для акустичного моніторингу стану легень та симптоматичної допомоги ураженим на COVID-19 у найскладнішій ситуації пандемії.

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

В.Н. Исаенко[1], В.П. Харченко[2], В.В. Астанин[3], А.А. Щегель[4], В.С. Олефир[5], А.И. Олефир[6], А.А. Олефир[7], О.В. Хомич[8], В.Н. Хомич[9]

Система акустического диагностирования и симптоматической помощи больным на COVID-19 в экстремальных условиях "Трембіта-Корона НАУ"

Национальный авиационный университет, просп. Любомира Гузара, 1, Киев, Украина, 03058
E-mails: [1]volodymyr.isaienko@gmail.com, [2]kharch@nau.edu.ua, [3]astanin@nau.edu.ua, [4]ashchegel@nau.edu.ua, [5]inf159vs@gmail.com, [6]oiolefir@ukr.net, [7]andolefir@gmail.com, [8,9]khomychov@gmail.com

Показана возможность быстрого налаживания массового производства систем для акустического мониторинга состояния легких и симптоматической помощи пораженным на COVID-19 в сложной ситуации пандемии.

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

Volodymyr Isaienko. Doctor of Biological Sciences, Candidate of Technical Sciences (Ph.D.)
Professor at the Department of Ecology of Faculty of Environmental Safety, Engineering and Technology, Rector of National Aviation University.
Education: Kyiv Technological Institute of Food Industry (National University of Food Technologies).
Research area: air pollution, environmental safety, climate changes, biotechnology.
Publications: 150.
E-mail: volodymyr.isaienko@gmail.com

Volodymyr Kharchenko. Doctor of Technical Sciences (Ph.D.), Professor,
Vice-Rector for scientific work of National Aviation University.
Education: National Aviation University.
Research area: management of complex socio-technical systems, air navigation systems and automatic decision-making systems aimed at avoidance conflict situations, space information technology design.
Publications: 540.
E-mail: kharch@nau.edu.ua

Vyacheslav Astanin. Doctor of Technical Sciences (Dr.Sci.Eng.)
Head of Mechanics Department of Aerospace Faculty of National Aviation University.
Education: Tashkent State University (National University of Uzbekistan).
Research area: mechanics of materials and structures, composite materials, impact engineering.
Publications: 170.
E-mail: astanin@nau.edu.ua

Ganna Shchegel. Candidate of Technical Sciences (Ph.D.)
Assistant Professor at Mechanics Department of Aerospace Faculty of National Aviation University.
Education: National Aviation University.
Research area: mechanics of materials and structures, composite materials, impact engineering.
Publications: 70.
E-mail: ashchegel@nau.edu.ua

Valentyna Olefir. Research engineer.
Teacher.
Education: Kyiv Polytechnic Institute.
Research area: computer simulation of chemical processes.
Publications: 5.
E-mail: inf159vs@gmail.com

Oleksii Olefir. Candidate of Technical Sciences (Ph.D.)
Associate Professor of the National Aviation University.
Education: National Aviation University.
Research area: control systems.
Publications: 78.
E-mail: oiolefir@ukr.net

Andrii Olefir. Magister of Engineering.
Research engineer.
Education: National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"
Research area: study of dynamic processes.
Publications: 30.
E-mail: andolefir@gmail.com

Olha Khomych. Magister of Medicine.
Assistant of the department of pediatrics of postgraduate education, National Medical University named after O.O. Bogomolets, Kiev, Ukraine
Education: Kyiv, National Medical University named after O.O. Bogomolets
Research area: clinical medicine.
Publications: 30.
E-mail: khomychov@gmail.com

Volodymyr Khomych. Doctor anesthetist resuscitator for children, Kiev Children's Hospital №1
Education: Kyiv, National Medical University named after O.O. Bogomolets
Research area: anesthesiology, resuscitation.
Publications: 10.
E-mail: khomychov@gmail.com