Technical Note

Complex System for Monitoring the Patient's Condition and Diagnosis of Bronchial Asthma

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ABSTRACT

In the present work, three versions of implementation of non-invasive bronchial asthma diagnostic system based on the author's technique of noninvasive diagnosis of bronchopulmonary diseases are considered. The offered variants of diagnostic system can be used both in medical institutions and at patient's home for the control of the patient's condition with the purpose of monitoring the dynamics of the disease during treatment, as well as for preventive purposes. Three variants of implementation of the diagnostic system with various complexity are considered. The results of a radiofrequency scanning of a human chest phantom with included heterogeneity simulating the presence of sputum in the human chest is a consequence of bronchial asthma.

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Keywords

Bronchial Diseases; Bronchial Asthma; Diagnosis; Computer Assisted Diagnosis; Microwaves; Patient Monitoring; Telemetry; Telemedicine; Diagnostic Imaging; Diagnostic Equipment

Introduction

Bronchial asthma is a chronic lung disease that affects people of all age groups. According to the statistics, more than 300 million cases of bronchial asthma of varying severity have been detected in the world today [1]. The prevalence of bronchial asthma in various countries reaches almost 20% of the total population. In addition, according to experts, the number of patients with bronchial asthma will only increase in the future. Therefore, the development of new methods for diagnosis and treatment of bronchial asthma, especially in young children, is a very urgent task.

Modern technologies, including telemedicine systems and mobile health systems [2] can play an important role in the diagnosis and treatment of a wide range of various diseases [3-6] like bronchial asthma [7]. One of the main directions for introducing technologies in medicine is the development of remote monitoring systems of human condition and telemedicine systems, which can be used to solve a wide range of problems, including:

- The decrease in the need for hospitalization of the patient and long stay under the supervision of a doctor in a medical institution;
- The reduction of the cost of medical care;
- The determination of the correctness for the chosen treatment method

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and timely correction of the list for prescription drugs;

• Increased probability of diagnosis in the early stages of the disease;

• Ensuring patients access to quality medical care in the absence of their abilities to directly access to the medical centers with modern diagnostic equipment and highly qualified specialists;

• The ensuring the possibility of medical advice without leaving home

A recent review [7] analyzed a large number of studies aimed at developing and implementing telemedicine systems for patients suffering from chronic bronchopulmonary diseases. In the paper, various options for implementation systems from the maintenance of specialized diaries in which patient activity and emerging symptoms of the disease are recorded to periodic videoconferences with medical personnel and also home monitoring systems are discussed.

A system is proposed that is a combination of a patient activity sensor, a GPS tracker and an air pollution sensor that are attached to the patient's body to transmit data to a central station to process and store them for further analysis [8]. Such system is designed to inform the patient about the need to reduce activity in the case of determining a high degree of air pollution to prevent an attack of the disease. It is also proposed to form an air pollution map by analyzing data from different patients to identify areas of excessive air pollution and inform patients about the need to refrain from visiting designated areas. The patient's current health status is not determined that it is a disadvantage of the system.

Individual monitoring of the patient's condition by analyzing wheezing recorded by three sensors placed on the patient's body is proposed [9]. Sound signals from the sensors are processed in a specialized device placed on the patient's body then they send the data through the GSM network to the server of the medical organization for further analyses by the doctor and the formation of a medical report. The disadvantages of such a system, which include the complexity of processing signals from sensors recorded in a noisy environment, the lack of information about the localization and severity of changes in the bronchopulmonary system, are very important to establish an accurate diagnosis and make a list and dosage of medicine.

In this paper, we propose the structure of a non-invasive diagnostic system for bronchial asthma and other bronchopulmonary diseases. Different levels and variants on the implementation of the diagnostic system for home use, emergency medical care, and monitoring of the patient's condition in inpatient treatment are presented.

Material and Methods

At the present time, various methods used in the diagnosis of bronchial asthma are known, including the general and biochemical blood analysis, sputum analysis, spirometry, chest radiography, computed tomography, and magnetic resonance imaging, etc. However, it should be noted that these methods are not without shortcomings. Therefore, a general and biochemical blood test, and sputum analysis require a long time to be performed. During radiographing chest organs, the patient is exposed to harmful ionizing radiation making it impossible to use this method frequently for analyzing the patient's condition for a long time. In addition, all these methods require the specialized expensive laboratory equipment, but accessing it is not available to all patients. To perform spirometric studies, the patient must perform special breathing maneuvers making this method unsuitable for diagnosing bronchial asthma in young children. In addition, all these methods, except CT scan and magnetic resonance imaging, do not provide information on the amount and degree of sputum localization in the patient's chest; however, it is quite important information for the treating doctor.

Currently, the field of radio electronics has been actively developing, dedicated to the development of inexpensive devices for self-monitoring of the patient's condition, based on the study of wheezing in the chest [10, 11] and compact spirographs [12, 13] sending measurement data to a remote medical server institutions for further analysis and the formation of a medical report. However, it should be noted that these devices are also incapable of providing information on the amount and extent of sputum localization in the patient's chest and they also have some specific deficiencies.

Therefore, at present, methods based on the use of low-power microwave radiation have been becoming increasingly popular for the diagnosis of bronchial asthma. The authors previously proposed a diagnostic method [14] based on the radio frequency scanning of the patient's chest by a microwave signal with a frequency from 1100 to 1500 MHz and the subsequent analysis of the transmission coefficient of the signal through the thorax. Experimental studies have revealed that this technique allows to detect the presence of sputum accumulations in the patient's chest and form a graphical representation of sputum distribution in the chest. Advantages of the proposed method are the ease of implementation and conduct of the examination, the absence of harmful effects on the patient, the lack of the need for breathing or other maneuvers, the ability to implement both complex systems for diagnosing and monitoring the patient's condition, and simple devices for home use.

In connection with the foregoing, the author's method based on the use of low-power microwave radiation was chosen as the basis of a complex non-invasive diagnostic system.

Discussion

Description of the proposed complex diagnostic system

The system of non-invasive diagnosis of bronchial asthma can be realized on three mutually independent levels:

1. An automated diagnostic system intended to use in medical institutions;
2. A more simple semi-automatic diagnostic system that can be used both in medical institutions and at home as well as in providing emergency assistance;
3. An individual system for monitoring the patient's condition, intended for home use, as well as for the patient's constant wearing and timely prevention of the disease attacks.

Let's consider each variant of diagnostic system in more details.

The block diagram of the automated diagnostic system intended for using in medical institutions is shown in Figure 1.

The basis of an automated diagnostic system is one of the options to implement a device for noninvasive diagnostics of bronchial asthma [15] which is a combination of a radiating module forming a microwave signal and emitting it using an antenna-applicator [16]; a module for receiving and processing a signal detecting microwave signals of a given frequency and performing the analog-to-digital conversion of detector's output voltage. The position of the radiating module is set by the positioning system which moves the module to implement the radio frequency scanning of the patient's chest. The module for receiving and processing the signal consists of an analog microwave channel to amplify and detect the

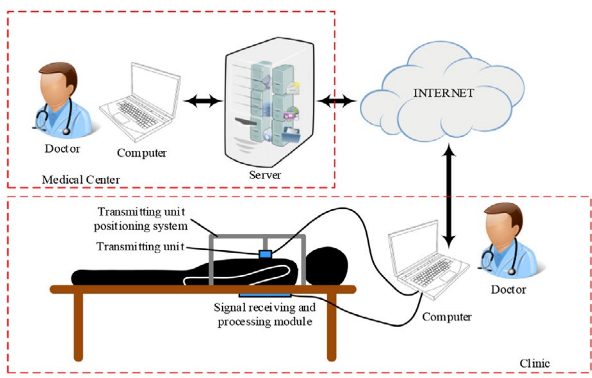

Figure 1: The block diagram of the automated diagnostic system

microwave signal, and a switched matrix of antennas (applicators); switching elements of which is performed depending on the position of the radiating module, and a digital circuit switches the antenna elements of the matrix and performs the digital conversion of the detector's output voltage and its transmission to the PC via a wire interface.

The PC of the medical center manages the positioning system of the radiating module, and transmits data between the radiating modules and the module for receiving and processing the signal, then also collects and processes the results of the survey. The results of the survey are presented graphically and contain information on the distribution and concentration of sputum in the patient's chest which facilitate the analysis of the examination results and diagnosis by the doctor. On the Internet, the results of the survey can be transferred to a remote medical center server for consultation with another doctor and clarification of the diagnosis.

Into the described automated system for diagnosing of bronchial asthma, additional sensors to control the parameters of the patient's vital activity can be integrated, for example, a temperature sensor, a digital stethoscope, a respiration, heart rate sensor, and an ECG which will allow a more complete picture of the patient's condition.

A structural diagram of a semi-automatic diagnostic system that can be used both in medical institutions and at home, as well as in providing emergency assistance, is shown in Figure 2.

Not having a cumbersome positioning system of the radiating module in the latter is the main difference between the semi-automatic systems of non-invasive diagnosis for bronchial asthma from the one shown in Figure 1. Instead, a laser displacement sensor is integrated into the radiating module allowing to track the movement of the radiating module during radio frequency scanning. The accuracy of such a positioning system is smaller,

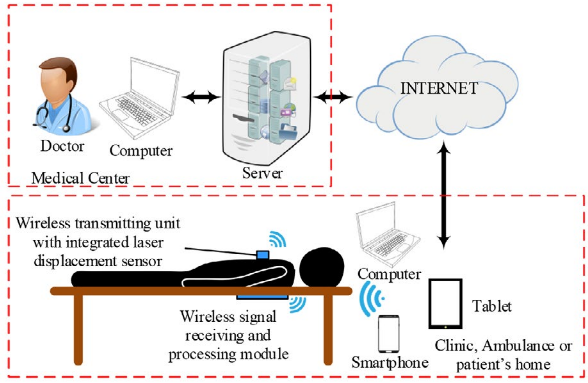

Figure 2: Structural diagram of a semi-automatic diagnostic system

but it is enough in order to perform radio frequency scanning of the chest [17].

Moving the radiating module is done manually by a certain path. In addition, to ensure the convenience of conducting a survey in a confined space ambulance or at home, the radiating module, the signal receiving and processing module are wireless and processing; the visualization of the measurement results is performed on a PC, tablet or smartphone. As in the case discussed above, the transfer of survey results to the remote medical center server is available for additional consultation.

The structural scheme for the third (individual) version of the non-invasive diagnostic system for bronchial asthma is shown in Figure 3.

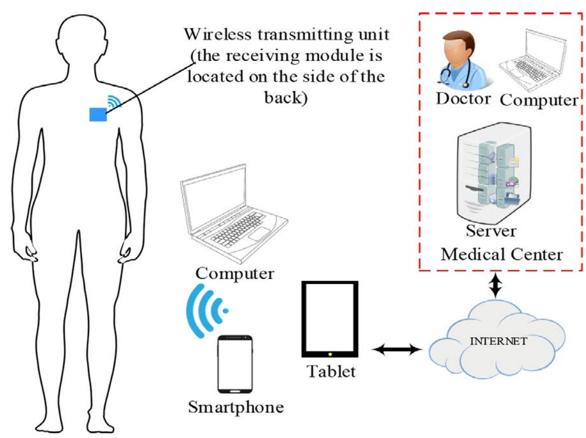

Figure 3: Structural scheme of the individual version of the non-invasive diagnostic system

The individual system for non-invasive diagnosis of bronchial asthma is a combination of two compact modules - radiating and receiving located on the chest and back, respectively. The position of each module is fixed and also does not change with time. The fixation point of the modules is determined on the basis of patients' the individual characteristics. Measurement of the transmission coefficient of the microwave signal is carried out at regular intervals. The measurement results are transmitted via a wireless interface to a PC, tablet or smartphone and recorded in an electronic diary. When the measurement results are outside the established limits, an alarm is generated displayed as a message on the screen of the mobile device and also can be sent to the electronic address of the medical center.

The described system can be useful for continuous rapid monitoring of the person's condition who is suffering from bronchial asthma during the day and then warn him about the need to take the medicine. In addition, it can be useful in medical institutions for monitoring the status of a patient in inpatient care and controlling the effects of medicines.

Technical description of the diagnostic system parts

Each described variant of the non-invasive diagnostic system for bronchial asthma is based on the combination of the radiating module and the signal receiving and processing module. The block diagram of the radiating module is shown in Figure 4.

The block diagram of the signal receiving and processing module is shown in Figure 5.

The radiating module and the signal receiv-

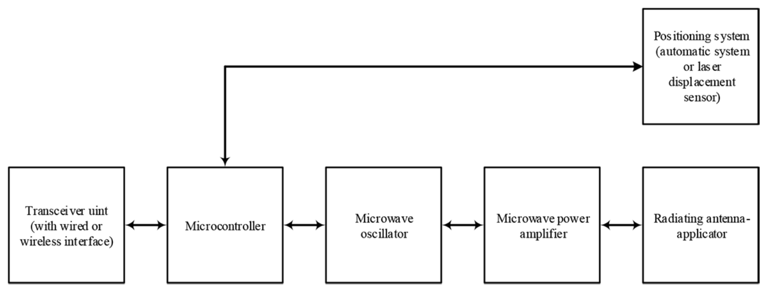

Figure 4: The block diagram of the radiating module

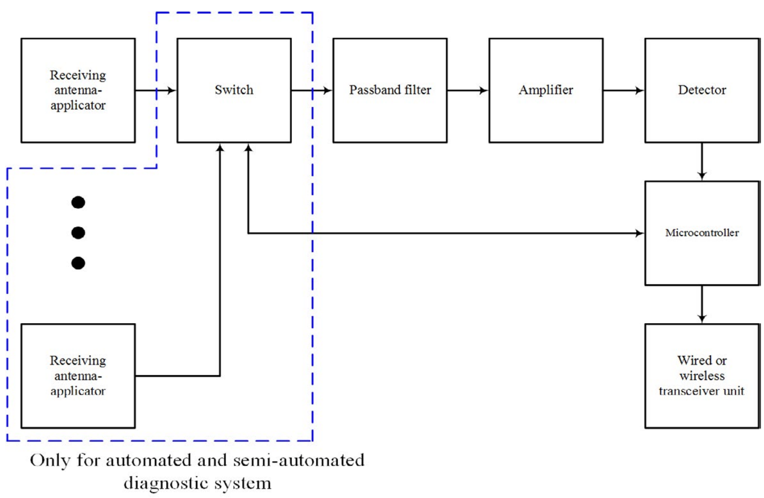

Figure 5: The block diagram of the signal receiving and processing module

ing and processing module are made in a compact form on the basis of modern radio electronic components. The modules are powered either from the PC's USB ports or built-in batteries in the case of wireless module implementation. The bandpass filter in the module for receiving and processing the signal ensures the transmission of the signal only at a frequency close to the probing signal generated by the radiating module leading to increasing the sensitivity of the diagnostic system. Built-in microcontrollers provide the control of positioning system, the system of switching elements in receiving matrix of antenna applicators, as well as the collection and transfer of measurement results for subsequent analysis and visualization.

The output power level of the radiating module does not exceed the established permissible norms ensuring the safety of using the diagnostic system for continuous monitoring.

The appearance of the prototypes for the radiating module and the module for receiving and processing the signal of the semi-automatic system for non-invasive diagnostics are shown in Figures 6 and 7, respectively.

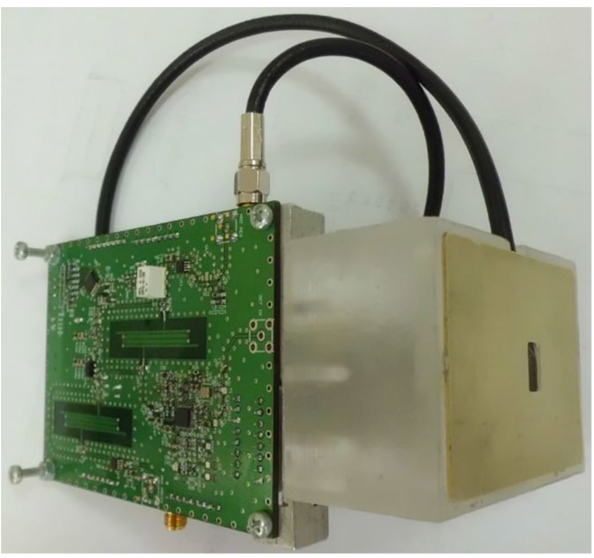

Figure 6: The prototype of the radiating module

Experimental results

To check the developed method and the diagnostic device, a phantom of the chest [16] was assembled, whose electrophysical parameters correspond to the tissues of the human body, to ensure that the diagnostic device works close to the real working conditions. Radio frequency chest scanning was carried out at several frequencies (1150 MHz, 1250 MHz and 1450 MHz) falling into the frequency range in which the greatest contrast is observed between the transmission coefficient of the microwave signal through the chest of a healthy person and a person suffering from bronchial asthma [14].

Interpolation method was used for the results of the measurements, on the basis of the obtained disparate data, to generate a three-dimensional graph of the transmission coefficient values of the microwave signal through the thorax which was directly related to the sputum distribution in the patient's chest and its two-dimensional projections for the subsequent analysis by a qualified specialist.

Figure 8 shows the results of a radiofrequency scan for a human chest phantom with an introduced heterogeneity - a hollow ball of radiotransparent material filled with 100 ml of 0.9% NaCl solution- simulating the presence of sputum in the patient's chest.

It can be seen from Figure. 8 that the transmission coefficient of the microwave signal through the phantom regions in which there is an inhomogeneity simulating the presence of sputum in the patient's chest is higher than the free areas of the phantom. In this case, the dimensions and shape of the inhomogeneity are displayed on the scan results sufficiently accurate for the diagnosis. The difference between the values of the transmission coefficient for the microwave signal through the phantom regions with the included heterogeneity and through the free areas of the phantom exceeds 10 dB, which is quite sufficient for reliable determination of the shape, boundaries and dimensions of the inhomogeneity.

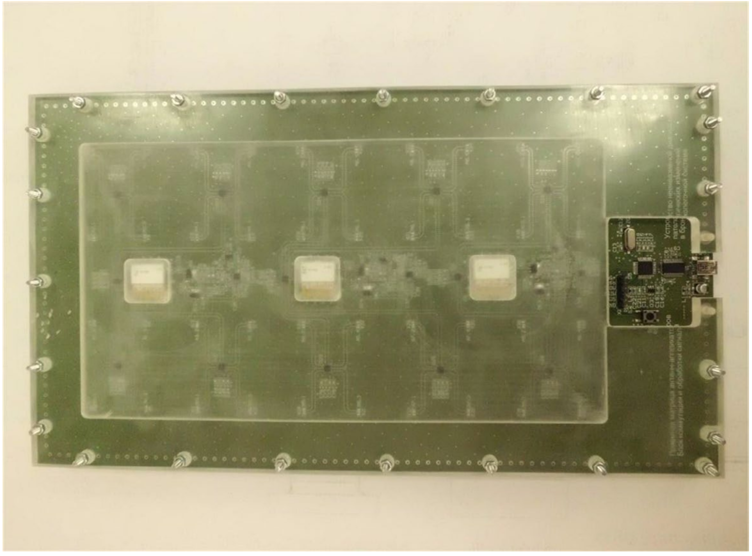

Figure 7: The prototype of the receiving and processing module

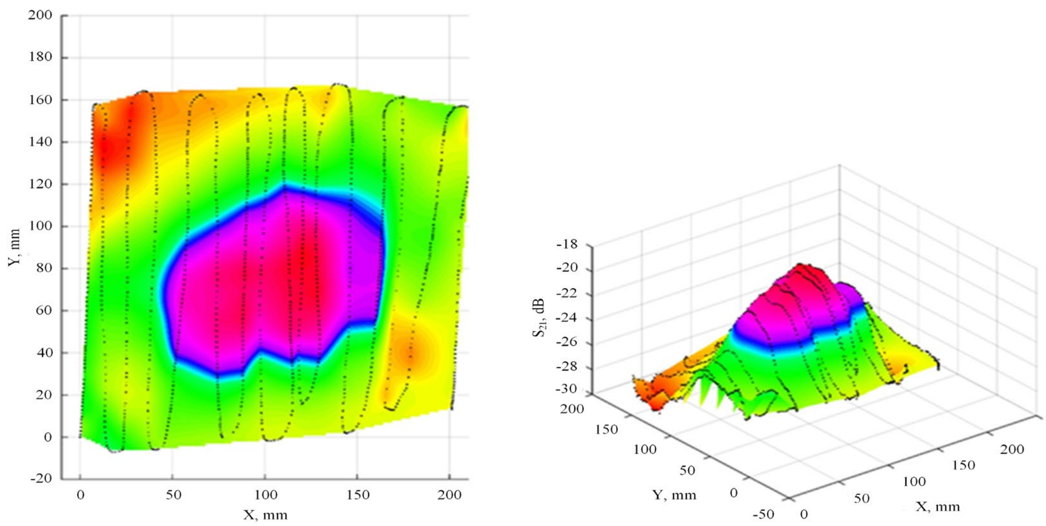

Figure 8: The experimental results of radiofrequency scanning

Conclusion

Thus, in the present work, three variants of the implementation for the non-invasive diagnostic system of bronchial asthma are considered based on the method proposed by the authors. The proposed variants of diagnostic systems can be used both in medical institutions and at home for the control of a patient's condition in order to monitor the dynamics of the disease during treatment, as well as for preventive purposes.

The use of available computing and communication facilities (laptop, tablet, smartphone, etc.) provides a reduction in the cost of the proposed diagnostic system for the end user; therefore, the diagnostic system can be equipped not only with central medical institutions in large cities but also with first aid stations in small remote cities and ambulances.

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Conflict of Interest

None

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