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A Remote System for Monitoring the State of Health of People with Chronic Diseases and Predicting Periods of Exacerbation

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Stages in the development of a system for remote monitoring of the state of health of people with chronic diseases are discussed, as are means of carrying out tasks at each stage, approaches to assessing ongoing state, and monitoring, controlling, and predicting exacerbations of chronic diseases.

Introduction

Medical support for patients with chronic non-communicable diseases (CNCD) is an ongoing challenge for healthcare systems throughout the world. This comes about as a result of a number of causes. Firstly, chronic diseases continuously progress and accompany patients throughout their lives; periods of remission are often interrupted by periods of exacerbation, which significantly reduce patients' quality of life [1]. Lack of attention to provision of medical support to such patients generally has the result that the disease acquires a neglected form. Secondly, World Health Organization (WHO) statistics show that chronic non-communicable diseases are the most common cause of death in the populations of all the countries of the world [2]. Thirdly, the forecast for the number of people falling ill with chronic CNCD is gloomy. Results from WHO studies show that — in an optimistic scenario — the number of cases of chronic CNCD will double by 2060 with mortality reaching 39 million people [3]. Fourthly, during periods of exacerbation of a patient's disease, significant time, material, and human resources are required to bring the patient to a state of remission. In this regard, many countries of the world are experiencing a growing understanding of the importance and necessity of solving the problem of monitoring the health status of people with chronic diseases, with prediction and early detection of periods of exacerbation of disease with the aim of providing the necessary medical care in a timely manner. Studies show that scientific centers are actively conducting research in this area using organizational and therapeutic/prophylactic measures [4–6]. Our approach to solving the medical support of patients with chronic CNCD is based on the wide use of information, computer, and telecommunications technologies, along with biomedical engineering technologies providing remote monitoring of patients' health status outside the clinic, in conditions of active living, ensuring the autonomy of the patient's information support in terms of identifying the first signs of disease exacerbation [7].

The aim of the present work was to develop a system for remote monitoring of the health status of people with chronic diseases outside the clinic, in active life conditions, using tools for assessing a set of biomedical indicators and predicting periods of disease exacerbation to provide prompt medical help.

Materials and Methods

Achievement of this goal requires solutions to a number of problems by a team of specialists from various fields of knowledge: physiology, biochemistry, biophysics, biomedical engineering, and information and telecommunication technologies. We will consider the main tasks which have to be solved to develop systems for remote monitoring of the health status of people with chronic diseases.

1. Grounding and Formation of a Set of Diagnostically Significant Indicators and Signs of Exacerbation of a Chronic Disease

A chronic noncommunicable disease, whether it be diabetes mellitus, arterial hypertension, heart rhythm disturbances, obstructive pulmonary disease, or cancer, is characterized by a set of diagnostically significant indicators which reflect changes in biochemical and physiological

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processes, the functioning of body systems and their interactions, and disorders of the body's metabolism. These changes are primarily reflected in the biochemical parameters of blood and urine, along with a set of indicators of heart rate variability characterizing the operation of the sympathetic and parasympathetic systems of the body [8]. Some chronic diseases mandate analysis of the performance of the heart and circulatory system. Long-term monitoring of diagnostically significant indicators can be continuous (in the case of monitoring cardiac arrhythmias) or periodic (monitoring of biochemical parameters of blood and urine, as well as indicators of respiratory system functioning). The specific composition of diagnostically significant indicators is formed taking into account the characteristics of the patient's chronic disease and the opinion of medical specialists. It should be noted that diagnostically significant indicators of a chronic disease and indicators reflecting exacerbation of the disease are quantitative indicators, while signs of the disease are qualitative. The transition from diagnostically significant indicators to signs (predictors) is based on indicator thresholds, which have their own values for each patient. These reflect the characteristics of a particular patient's body and vary depending on the stage of a chronic disease, the influence of environmental factors, and the patient's age.

2. Construction of Mathematical and Logical Models ofChronic Noncommunicable Diseases for the State of Remission and Stages of Exacerbation of the Disease

Mathematical and logical models of a CNCD describe various stages of the disease based on a set of diagnostically significant indicators and disease signs and are used to classify the current physiological state of the patient's body [7]. The patient may be in remission or in some stage of exacerbation of the chronic disease. The current state of the body of a patient with a CNCD is assed by constructing a multidimensional space of diagnostically significant indicators and signs, which reflect the areas corresponding to remission and the stages of exacerbation of the disease in accordance with the models developed and constructing the vector of the ongoing state of the patient, and determining a measure of the proximity (distance) from the vector of the current state to the boundaries of the areas reflecting the stage of exacerbation of the CNCD. Prognostication of the disease and identification of periods of its exacerbation require knowledge of additional indicators reflecting the dynamics of how the vector of the current state is shifting in the multidimensional space of signs. The rate of displacement of the vector of the ongoing state is influenced by the individual characteristics of the patient's body and its adaptive reserves. In this regard, mathematical models are developed using differential or integral equations expressing functions of time with variable coefficients taking account of the individual characteristics of the body. There are different versions of the use of matrix models which will reflect changes in the state of the body at fixed points in time.

3. Construction of a Set of Certified Instruments and Research Methods Detecting Biomedical Signals and Assessing Diagnostically Significant Indicators in Remote Monitoring of Patients' Health Status in Active Living Conditions

Solving this problem requires knowledge of the functionality and characteristics of a wide variety of home medical devices (portable blood pressure monitors, heart monitors, biochemical blood and urine analyzers, means for assessing blood coagulation parameters, continuous monitoring of blood glucose levels, etc.), the possibility of integrating these into a single portable patient information/measuring system based on a portable computer (high-performance smartphone) for processing and analyzing biomedical signals and data, assessing the current state of the patient's health, providing information support to the patient during the development of an exacerbation of chronic disease, transmitting information about the current state to a server at a medical institution for long-term monitoring of health status, analysis of the changes in indicators, prognostication of exacerbation of a chronic disease, and detecting exacerbations of a chronic disease at early stages of their development [7].

4. Development of a Technology for Remote Monitoring of the Health Status of Patients with Chronic CNCD and Algorithms for Collecting Biomedical Signals and Data

The technology for remote monitoring of the health status of a patient with CNCD determines the sequence and frequency of sampling, recording of biomedical signals, and assessment of diagnostically significant indicators and signs of a chronic CNCD. Physiological indicators of the body during life activity are characterized by variability. In a healthy body, this variability is due to cyclic (daily) processes and is within the limits of the individual norm. For a patient with a disease, including a chronic disease, this variability is also within certain limits, determined by the severity of the disease. Transition of the disease from

one stage to another is accompanied by a slow shift in the boundaries. It should be noted that in terms of determining the sequence and frequency of assessment of diagnostically significant indicators of a CNCD, indicators such as blood pressure and blood sugar should be assessed at least twice a day, some biochemical parameters of blood and urine in the early stages of development should be evaluated once a day, while once a week is appropriate for some other indicators. However, ensuring high prognostic accuracy and reliability and detecting exacerbations of a chronic disease at the early stages on the basis of borderline values of diagnostically significant indicators of chronic CNCD require increases in the frequency of their assessment, monitoring of the displacement of the boundaries of oscillatory processes with changes in the severity of the disease, and application of the correct mathematical models taking account of the dynamics of the disease. This approach allows models for predicting disease exacerbations to be personalized and the functioning of remote monitoring systems to be adapted to the characteristics of the functioning of the patient's body and the development of the chronic disease.

5. Development of Algorithms for Monitoring and Predicting the Health Status of Patients with Chronic CNCD and Detecting Disease Exacerbations at an Early Stage

As noted in the previous paragraph, the frequency of assessing and monitoring the ongoing physiological state of the patient should change depending on the dynamics of diagnostically significant indicators of chronic disease. For each diagnostically significant indicator, a plot of its dynamics is constructed and its numerical values are used to find an approximating function, i.e., a model of the dynamics of the diagnostic indicator [9]. After evaluating the next value of a diagnostically significant indicator, the approximating function needs to be refined. The prognostic model is based on extrapolation of the approximating function over a certain period of time and achievement of a threshold level at which a period of exacerbation of the chronic disease develops. In this regard, adjustment of the approximating function at each stage of the ongoing assessment of the patient's physiological state becomes necessary, as this helps improve the accuracy of short-term prognosis and identification of the onset of an exacerbation of the disease. As a set of diagnostically significant indicators is used to monitor the patient's ongoing physiological state, the procedures for determining the approximating function of changes in the indicator and extrapolating and prognosticating the exacerbations of the disease are carried out for each of the indicators. This information is sent to the doctor, who assesses the risks and forms a conclusion regarding implementation of further therapeutic and preventive measures for the patient concerned.

Conclusions

The priority tasks in constructing a system for remote monitoring of the health status of people with chronic diseases and predicting periods of exacerbation and identifying disease exacerbations at an early stage are considered and ways to solve them are proposed. Taking account of the approaches proposed, the remote monitoring system developed here is an intelligent information-measuring multi-level system, whose algorithm provides continuous monitoring of the patient's ongoing physiological state, with construction of a plot of the dynamics of a set of diagnostically significant indicators of a chronic disease approximating the function and its extrapolation for a given period to obtain a short-term forecast of physiological state and early detection of exacerbations of chronic diseases. The system adapts the frequency of monitoring the patient's physiological state, taking account of the characteristics of the processes occurring in the body and providing information support to the patient in case of exacerbations of the disease using the patient's portable computer; the system for remote monitoring and control of the patient's condition can operate autonomously when communication with the hospital server is unavailable. The prospects for the development of a remote monitoring system are associated with increases in the intelligence of many of its functions, reducing the burden on the doctor in terms of performing routine monitoring operations.

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