Basics of remote monitoring systems design

The need to expand the availability and improve the quality of medical services as population size increases, especially with growth in the proportion of elderly people, is driving a search for solutions to the diagnosis and treatment of diseases affecting broad sectors of the population living not only in cities, but also in remote population centers. An effective solution to this problem is provided by use of telemedical monitoring health status of people for preventing disease and predicting the risk of exacerbations of chronic diseases.

Development of the Structure of a System for Remote Intelligent Monitoring of People's Health Status.

A system for monitoring human health and predicting disease exacerbations must solve a set of tasks linked with recording signals characterizing the activity of the body systems, processing and analyzing biomedical information, assessing ongoing body status, identifying the dynamics of changes, and predicting disease exacerbations. Solution of this set of tasks clearly requires a multi-level structure, each level optimizing the solution of a particular task.

The first level of a hierarchical monitoring system (patient's portable monitor) addresses the task of objective and reliable recording of a set of biomedical signals and measures of body system activity. Signal recording errors are minimized by reducing the influence of the portable monitor on body system functioning and the patient's usual activities. Probes and sensors in the patient's portable monitor should support noninvasive assessment of medical-biological measures of the human body, be biologically compatible, and not influence the temporospatial distribution of the biomedical signals recorded. Reliable long-term recording of biomedical signals requires the portable monitor to have a high level of operational autonomy, using preliminary signal processing at the next level of the system. The use of intelligent algorithms for recording and transmitting biomedical signals at the second level of the system – the biomedical signal receiver – significantly decreases current consumption and increases device autonomy.

The intelligent operation of the portable monitor means that when the patient's status corresponds to the individual norm the device switches to background mode. The only active channel in this mode is the ECG channel. The biomedical signals receiver, i.e., the second level of the system, assesses heart rate variability, and when the individual norm is exceeded activates additional biomedical signal recording channels in the portable monitor and changes the biomedical signal recording parameters to increase accuracy and the significance of assessments of the patient's ongoing health status. The radio signal transmission power from the portable monitor to the receiver must be restricted to tens of milliwatts, which is sufficient for transmitting the signal to the signal receiver in the patient's vicinity. This supports additional autonomy in the operation of the portable monitor. The target function of the first level of the system is to ensure accurate and significant recording and transmission of signals in conditions of long-term autonomic functioning.

The second level of the system is the signal receiver. This carries out preliminary processing of biomedical signals, assessing diagnostically important measures characterizing the patient's health status and assessing ongoing health status, controlling the operating mode (connecting additional signal recording channels), and altering the recording channel parameters of the portable monitor. This analyzes measures of body system functioning, generates patient notification signals when the parameters being monitored go beyond the individual limits, and transmits biomedical information via WLAN to the server in the healthcare institution monitoring health status and predicting exacerbations of chronic diseases. Intelligent operation of the second level of the system consists of changes in the signal processing algorithms when patient status monitoring values go beyond individual normal ranges. For efficient use of operative memory, the duration of storage of diagnostically significant measures of the patient's health status should not be longer than one week. These values are recorded for longer patient status monitoring periods on the server at the healthcare institution. Performance of all these tasks at the second level of the system requires a high-performance processor.

Given the current level of development of computer technologies, this level can be run on a smartphone or tablet using an independent or mains power supply. The target functions of the second level of the system are to provide reliable assessment of the patient's status and transmit medical-biological information to the third level for long-term monitoring and prediction of the patient's health status.

The third level of the system consists of cloud and server technology at the healthcare institution monitoring the patient's health status. This is the level at which detailed analysis of the dynamics of the functional status of the body systems and integral assessment of health status are performed, individual normal values of the patient being monitored are updated, the criteria for disease diagnosis and prediction of exacerbations are evaluated, and reports of functional changes in the body systems constituting threats to the patient's health are generated for the treating doctor. The intelligence aspect of the operation of the system at this level consists of alterations to the signal processing and analysis algorithms to enhance the accuracy and reliability of the diagnosis of functional impairments to the body. The target functions of the third level of the system are to conduct long-term monitoring of patient health and predict exacerbation of patients' diseases.

The fourth level of the system is the treating (family) doctor's microprocessor system that operates on a mobile (tablet) or desktop computer. The doctor receives the necessary information on the patient's current status, the dynamics of changes in health status during long-term monitoring, and predictions of health status on forth- coming days. At this level, the treating doctor can be advised regarding typical decisions on the use of medical technologies and medicines to normalize the patient's health status when life- and health-threatening function- al impairments arise.

Information interactions of the second, third, and fourth levels of the monitoring system occur via WLAN. The server at the healthcare institution receives patient healthcare information at the second level of the system; in the opposite direction, the patient's mobile device receives program updates based on the long-term monitoring of criteria for assessment of the patient's current status, control commands for running the intelligent mode for recording and processing biomedical signals. Use of WLAN between the server in the healthcare institution and the doctor's computer provides the doctor with access to the patient's data, with monitoring of the patient's health status, and access to the patient's medical records independently of time and place. The doctor, using the cloud, can adjust the monitoring program and the assessment of ongoing health status and the prediction of the patient's health status. The target functions of the fourth level of the system are to provide monitoring of the patient's health status and to allow the treating (family) doctor to take decisions, and to provide the doctor with access to the patient's medical records.

In accordance with this reasoning, a generalized structure for a multilevel intelligent system for remote monitoring of health status is proposed (Fig. 1).

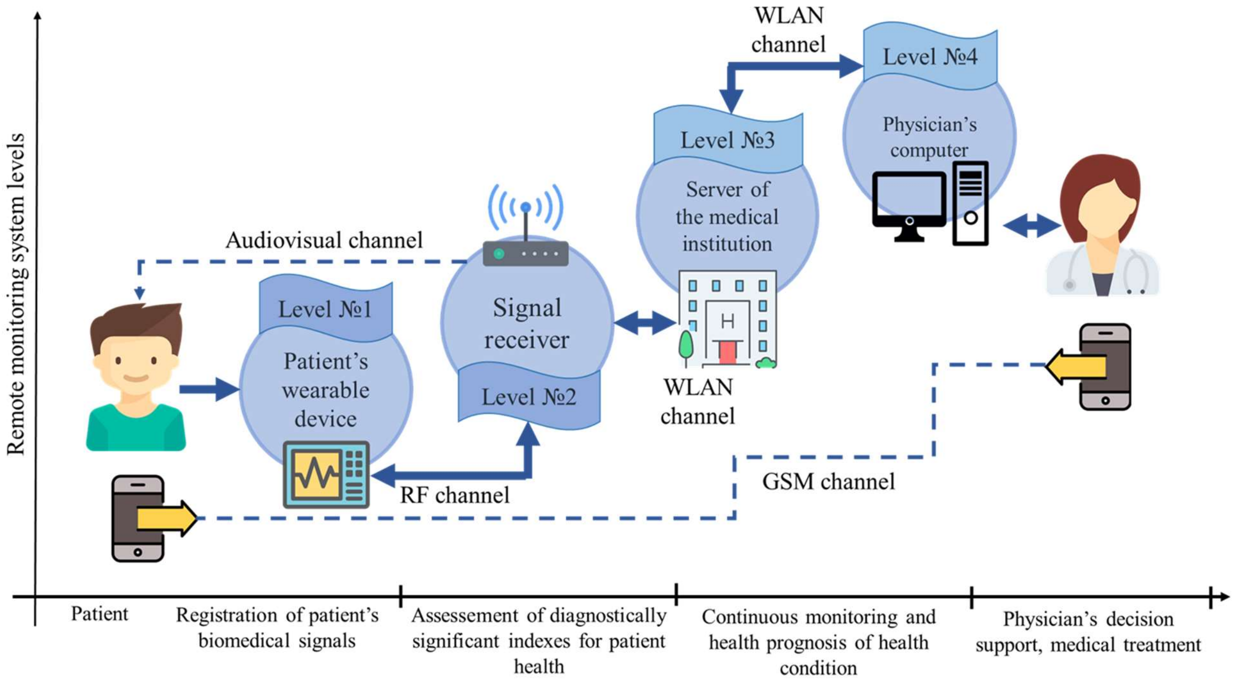

Figure 1 – Structure of remote monitoring system.

This generalized structure is suitable for describing virtually all intelligent remote systems monitoring health status and predicting disease exacerbations. There will be fundamental differences in the hardware part of the mobile device and the programming for all levels of the system. Assessment of the current status of a patient with a particular chronic disease evidently requires well defined algorithms resolving the rules and criteria for diagnosing disease and predicting exacerbations of dis- ease. The production of the hardware part of the system at the first level and the programming will be determined exclusively by the target function of the overall remote monitoring system.

Development of an Algorithm for remote intelligent monitoring system

The essence of remote intelligent monitoring of a person's health status is changing operating modes and the characteristics of the patient's mobile device, as well as the algorithms for processing and analyzing biomedical information at the second and third levels of the system when the patient's health status parameters deviate from the individual norm. A generalized algorithm for remote intelligent monitoring of a patient's health status is shown in Fig. 2.

In this algorithm, after activation of the overall sys- tem by the second level of the system (the patient's smartphone) and inputting of patient data, the task of the initial operating mode of the mobile device is to record bio-medical signals from the patient and transmit them to the patient's smartphone. This assesses the patient's current status. When measures of current patient health status are consistent with the individual norms, the normal values can be updated and continuous monitoring can be continued.

When measures of current status diverge from individual normal values, the second level of the system activates additional signal recording channels on the mobile device and adjusts the characteristics of the channels, then performing detailed analysis of the patient's health status, providing information on the patient's health status to the patient or the doctor by transmitting medical data from the healthcare institution server to the doctor's computer. The doctor in turn can perform a detailed analysis of patient health status measures to inform the recommendations for the patient or take decisions regarding provision of urgent care.

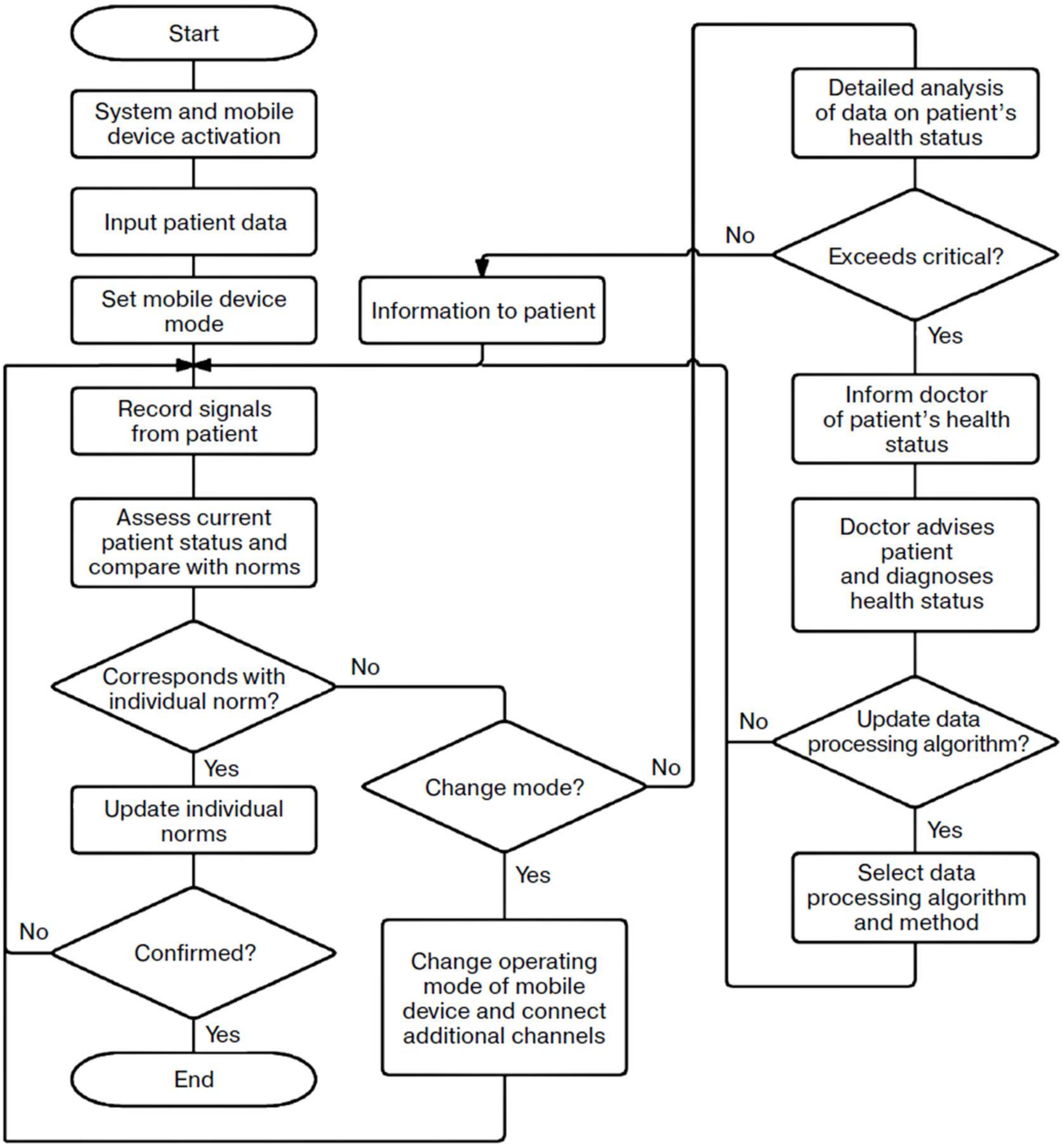

Figure 2 – Generalized intelligent monitoring algorithm.