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V.M.Glushkov Institute of Cybernetics of NAS, Ukraine,
Universidad Politécnica de Madrid, Spain,
Hasselt University, Belgium, University of Perugia, Italy,
Institute for Informatics and Automation Problems, NAS of the Republic of Armenia
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WIRELESS SENSOR NETWORKS WITH ELEMENTS OF ARTIFICIAL INTELLIGENCE FOR MEDICINE

Volodymyr Romanov, Igor Galelyuka, Oleksandr Voronenko, Oleksandra Kovyrova, Ozar Mintser, Tatyana Pyatchanina

Abstract: *The integrated digitalization of medicine, the use of the AIIoT (Artificial Intelligence IoT), and networks of medical wireless sensors offers new opportunities to remotely support the quality of life of chronically ill patients, the elderly, post-corona pandemic people and athletes and professionals with heavy physical or mental workloads. Wireless sensor networks and computer remote means of maintaining quality of life include smart wearable medical sensors and analog interface. The sensors are intended to monitor heart rate, respiration and blood pressure, determine skin moisture, patient's position and other medical parameters in real time. Miniature interfaces are intended for data acquisition, analog-to-digital conversion, data preprocessing of medical parameters received from wearable medical sensors and data communication to remote diagnostic center. The current state and prospects for the development of these tools are discussed in the publication.*

Keywords: *wireless smart sensor networks, medical information communicators, quality of life, application software*

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Introduction

Digitization of the main areas of human activity has led to the emergence of digital medicine. Digital medicine is primarily focused on disease prevention and ensuring the necessary quality of life. Based on this, at the present stage of development of artificial intelligence (AI) technologies, the following basic directions of digital medicine development can be identified:

1. Development and creation of wearable medical monitors, which are built on the base of smart sensors for real-time measurement of basic medical parameters and integrated into a wireless sensor network (WSN).

2. Development and creation of wearable computer means of preprocessing of measured medical parameters.

3. Development and creation of wearable means of transmission of medical parameters to remote diagnostic centers.

4. Development and creation of remotely controlled wearable injectors for the injection therapy.

Digital technology is designed to provide health care to millions of people. Their development and implementation in medical practice has already begun. However, if wearable medical monitors with smart sensors, which are integrated into wireless networks, and remote injectors are already used in medical practice, the diagnosis based on the transmitted parameters to remote medical centers remains the prerogative of the doctor. Such centers store data on the patient's diseases and services, but the current level of artificial intelligence does not yet allow such centers to use of a particular method of medical care.

Work objectives

Work objectives are developing the wireless smart sensor networks and communicators for medicine.

Smart sensor network developing

The rapid development of microelectronics makes it possible today to master inexpensive wearable medical monitors and provide them not only for chronically ill patients, but also for post-corona pandemic people, and people who are actively involved in sports or undergo heavy physical or psychological stress in the performance of their professional duties. As an example, consider the latest basic solutions for the development of wearable medical monitors, which are offered by leading companies in the microelectronics. All multi-parameter wearable medical monitors are subject to the same requirements: they must be valid, miniature and work for a long time without replacing or recharging the batteries. To meet these requirements, many well-known companies are developing smart interfaces for wearable medical sensors, which are intended for pre-processing of real-time measured medical parameters [Broeders, 2021]. Such parameters include the level of oxygen saturation, electrocardiogram, photoplethysmogram, blood pressure, respiratory rate, body temperature and others, many of which have recently been measured only in clinic. Monitoring of these parameters is important for the elderly, patients in the postoperative period, for post-corona pandemic people or patients who have suffered a serious illness and are at risk. In a pandemic, it is necessary to restrict people from visiting clinics. In addition, the monitoring of medical parameters, as already mentioned, is important for people who play sports or have heavy physical or psychological stress in the performance of their professional duties. Therefore, the use of wearable multiparameter medical monitors out of clinic is an urgent need of modern medical practice. Note that on the market there are quite a lot of wearable medical systems that simultaneously measure several medical parameters. These can be heart rate monitors with motion sensors, heart rate monitors, which are combined with skin impedance meters and which allow you to record stress or analyze the patient's condition during sleep. In most cases, in such monitors, each measurement is performed using a separate smart interface. As a result, many of the same type of integrated microelectronic circuits (ICs) are used, each of which contains an analog-to-digital converter (ADC), processor, primary and secondary power supplies and other necessary components. This complicates the wearable medical monitor, increases its size and power consumption, and, most importantly, reduces operational reliability. Hence the replacing a number of interface ICs with a single chip will improve the quality of the monitor. An example of such an interface is the ADPD4000/ADPD4001 IC from Analog Devices Company. The functional diagram of interface is shown in Figure. 1. It contains an 8-channel multiplexer with two programmable gain amplifiers, two band pass filters, two integrators, a 14-bit ADC with a maximum sampling frequency of 1 MHz, a processor, LED drivers and excitation signal sources.

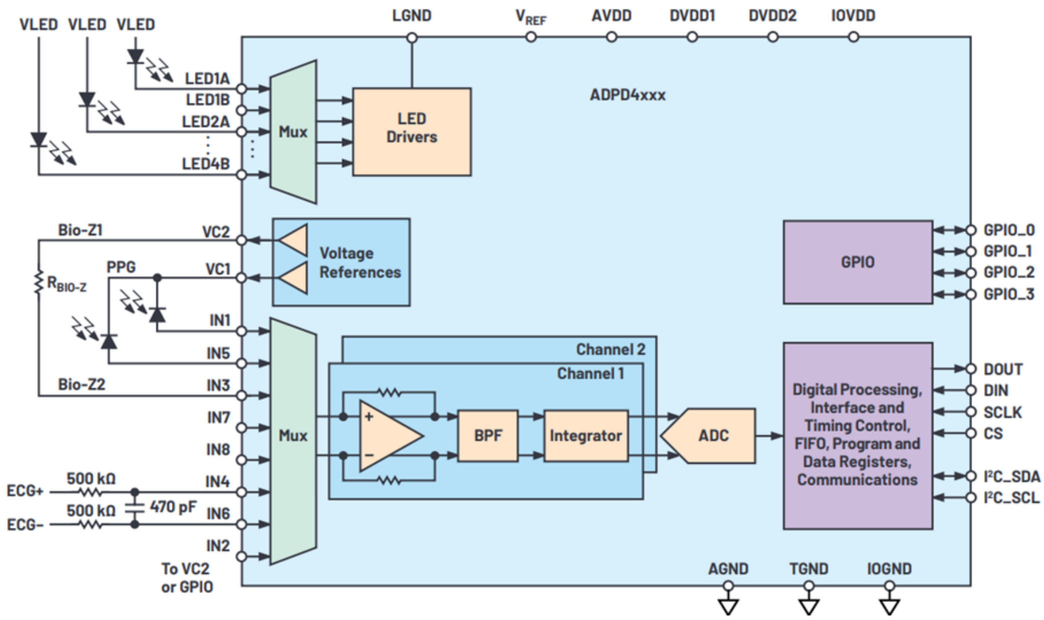

Figure 1. Functional diagram of interface ADPD4xxx for multiparameter sensors

With this interface, you can measure various medical parameters, including using it as an interface for optical signals, for example, to measure heart rate or blood oxygen saturation. In this case, low-level photocurrents are measured, for which a high-impedance input amplifier is used. This interface can be used to process of cardio signals. In addition, it generates excitation signals to measure the impedance of the skin (electro dermal activity) or the reference electrode when measuring biopotentials. The interface can be pre-programmed for one or more configurations, as well as for data acquisition at certain time intervals. In addition, this interface does not require additional computing resources for digital processing of measured analog signals, which makes it possible to minimize the power consumption of the wearable monitor as a whole. The results of measurements of medical parameters can be stored in FIFO memory up to 512 bytes. The interface provides synchronization of measurements of different medical parameters to determine the correlation between them. In Figure 2 it is showed how this multiparameter interface measures the ECG synchronously with the measurement of the pulse wave (PW) for calculating blood pressure, which is especially important for patients with hypertension [Carriero, 2021, Romanov et al, 2016]. Cardiac signals typically have amplitude of 0.5 mV to 4 mV and are measured in the frequency band from 0.05 to 40 Hz. These signals go with the heart rate, and the shape of the pulse wave itself can be used as a characteristic of the heart, including a preliminary prediction of possible heart disease, such as arrhythmia or hypertension.

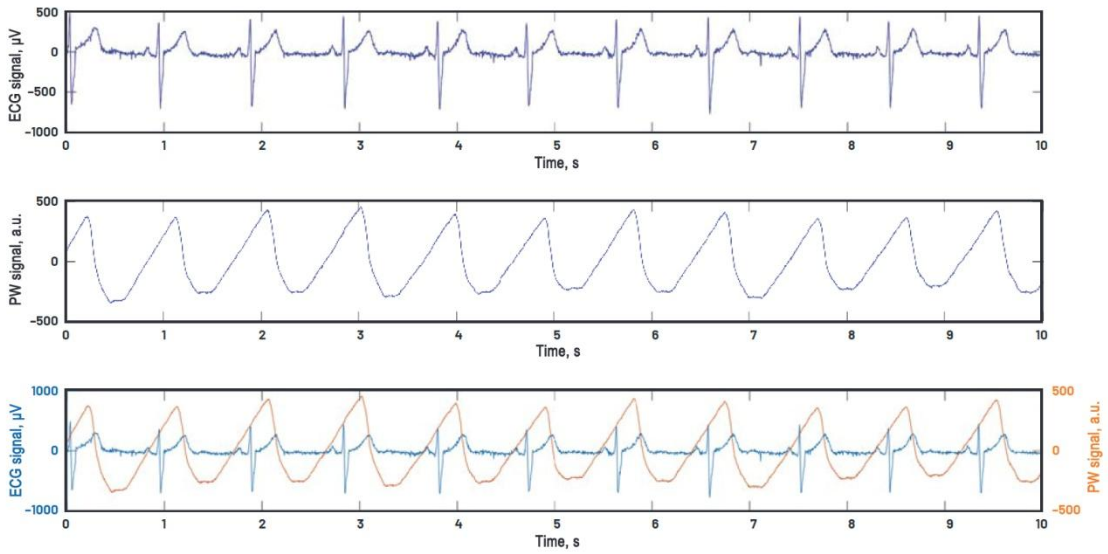

Figure 2. Diagrams of simultaneous measurement of ECG and PW signals

Given that both wet and dry electrodes can be used for long-term monitoring of heart function, the interface ADPD4000 provides the required quality of the measured cardio signal regardless of the type of electrodes. This is due to the fact that instead of measuring the potential at the output of the electrode, the interface measures the amount of electric charge on the capacitor, which due to the optimal choice of time constant of the input RC-circuit and sampling frequency of the capacitor is virtually independent of skin-electrode contact resistance. Another advantage of the ADPD4000 IC is the low power consumption, because the sample the cardio signal is provided with RC-circuit, so the maximum consumption of this IC is not more than 200 microwatt. For optical measurement of pulse waves in IC ADPD4000 there are eight programmable drivers of light-emitting diodes (LEDs). This is due to the fact that many medical systems simultaneously use LEDs of different wavelengths. Depending on the configuration, the ADPD4000 interface provides measurement of signals such as heart rate, blood oxygen saturation, hydration or dehydration. Each of the two input channels has a programmable amplifier. The signal-to-noise ratio of the input channel of the interface is not less than 100 dB, which makes it possible to use it for measurements sensitive to electromagnetic interference. Many wearable medical monitors are designed to measure the conductivity of the skin, in particular, to record electro dermal activity, stress or mental state of the patient. The ADPD4000 IC supports the following measurements. Because this interface has an 8-channel multiplexer, its inputs can be used to measure body temperature or monitor patient activity when measuring medical parameters.

One of the methods of vascular screening is photoplethysmography. This express method is based on determining the volume of blood in the microcirculatory tract. The principle of operation of wearable optical modules for photoplethysmography is as follows. The light source, usually an LED, irradiates the patient's finger, and the photodetector, depending on the amount of light reflected or absorbed by tissues, measures the shape of the pulse wave, which is caused by periodic changes in blood volume with each heartbeat, and heart rate and variability. The light flux can be directed through the finger or earlobe measuring the amount of light transmitted or reflected by the finger or earlobe, Figure. 3.

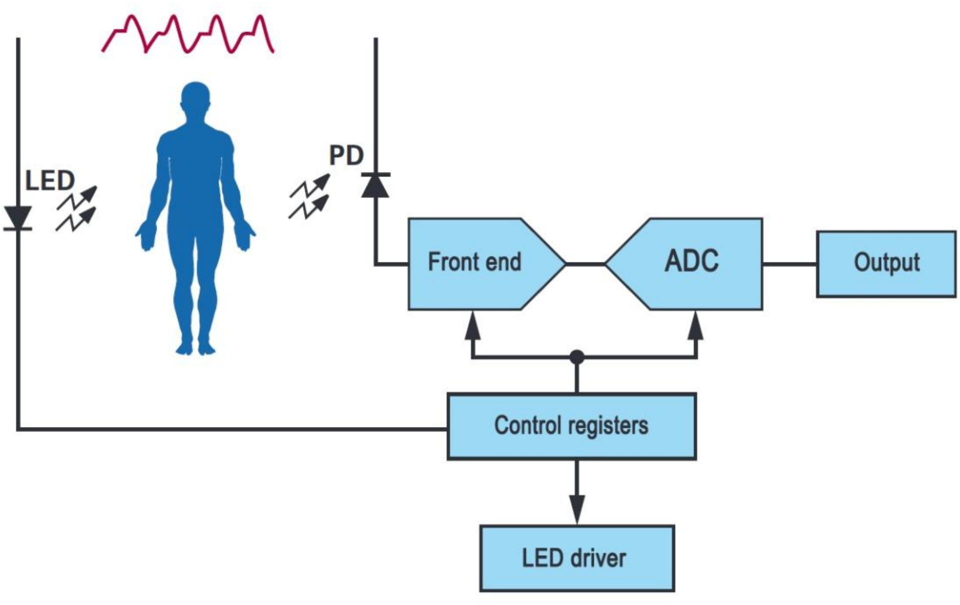

Figure 3. Functional diagram of the optical photoplethysmograph

The use of wireless sensor networks and wireless devices in medicine makes it possible to improve the quality and efficiency of medical services through the ability to remotely monitor the condition of patients and receive valid information about the patient's condition out of clinic, usually in real time for preliminary diagnosis. With such remote medical monitoring, the patient can be at home, which is especially important in a pandemic. In the general case, the patient's remote medical monitor consists of a number of wearable sensors, a remotely controlled wearable injectors and a wireless data exchange module, as shown in Figure 4 [Romanov et al, 2016].

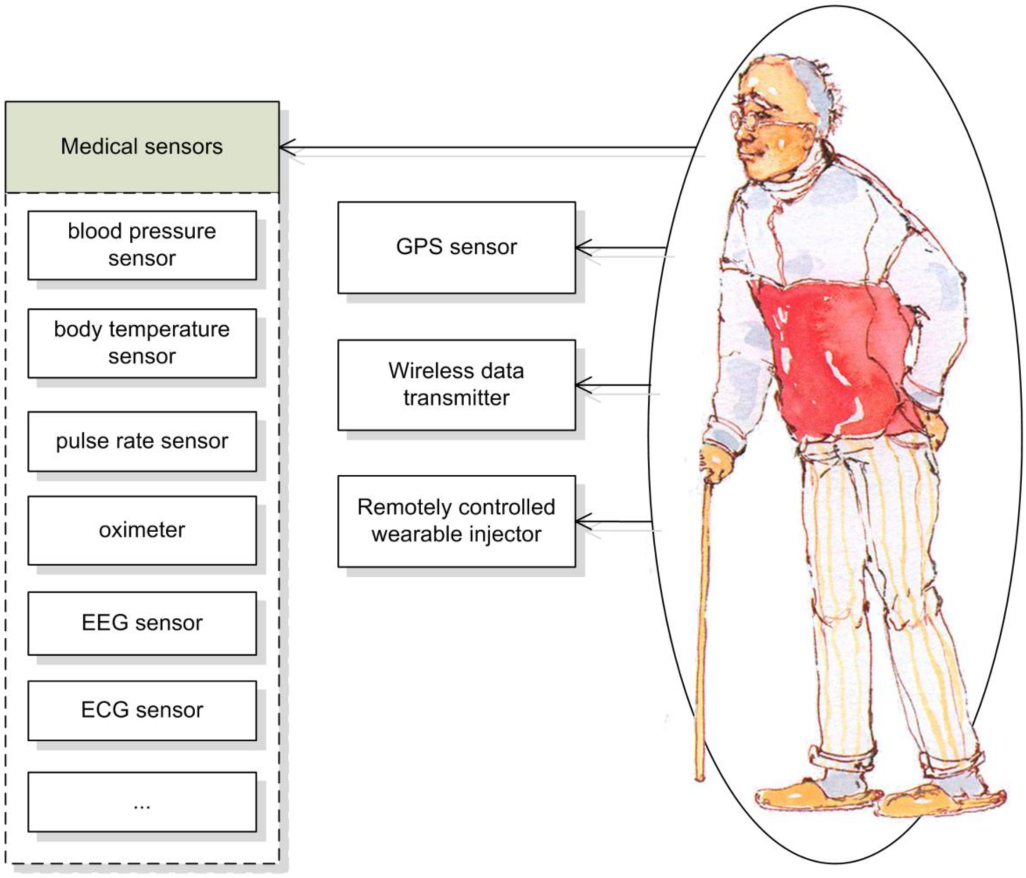

Figure 4. Remote medical monitor

The wearable sensors are connected to the wireless communication module via wires or, more often, via a short-range wireless protocol, such as Bluetooth.

Often a mobile phone or tablet computer can serve as a wireless communication module. In addition to transmitting data from wearable sensors to a remote server of a medical institution, the wireless data exchange module is used for remote control of wearable injectors.

Remote medical monitoring is not so much in the creation of channels for wireless transmission of medical data, as in the organization and maintenance of the necessary infrastructure for the operation of such monitoring systems. This means the organization of Internet services, storage and protection of data on a remote server, application software development, integration of wireless medical sensors, devices and actuators at the patient level, long-term operation of wireless sensors and devices in the "field" virtually maintenance-free, data processing, including "big data" by the cognitive diagnostic center. This approach to develop a remote medical monitoring system ensures the transmission of data in real time.

Currently, there are many standards and protocols in the world for wireless systems, which should be used in modern medical monitoring systems. Among them are the following: Bluetooth, Bluetooth LE (or Bluetooth Smart), IEEE 802.15.4, ZigBee, Thread, WirelessHART, etc. An example of a remote medical monitoring system that uses several wireless communication protocols is shown in Figure 5.

For example, ZigBee protocol can be used to develop a wireless monitoring network that is designed to operate within clinics. The ZigBee Pro stack was used to organize wireless data transmission in such a network. The main control unit of this network is the coordinator, which ensures the formation and operation of WSN. In addition, the coordinator provides data acquisition, data processing, data visualization and data transmission to a remote diagnostic center. The network coordinator can additionally communicate with the cloud environment, the Internet or a higher-level system. The doctor's workplace is a PC with a special ZigBee / USB adapter. The main disadvantage of using ZigBee-compatible wireless networks is the inability to use wireless medical monitors outside the clinic.

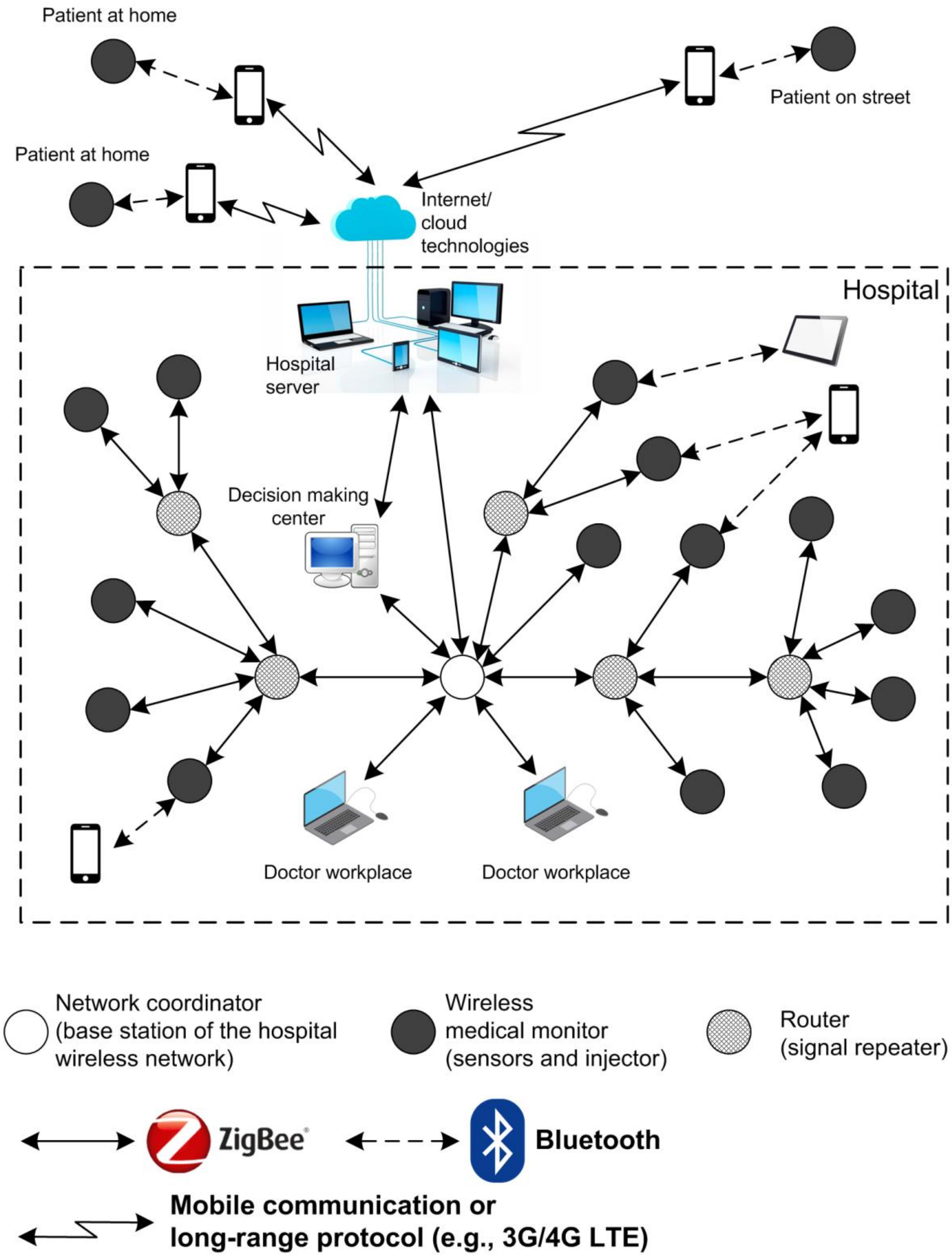

Figure 5. An example of a remote medical monitoring system

Bluetooth version 5.0 (and higher) has a number of significant advantages. Data transmission with sufficient validity is guaranteed at a distance of up to 100-150 m, which can be compared with the range of reliable communication of wireless nodes based on the ZigBee protocol. Indoors, reliable data transmission is guaranteed at a distance of 30-35 m, which satisfies the conditions of the applied task of medical monitoring. The maximum message size is 255 bytes, which allows you to simultaneously transmit in one packet several medical parameters. Important for the medical monitoring system is the ability to connect up to 20 measuring nodes to a star network. To form a network with a large number of measuring nodes based on the Bluetooth 5.0 protocol, it is possible to deploy a network of Bluetooth Mesh, which can be used from hundreds to several thousand measuring nodes, which allows remote monitoring of patients in large clinics. To supports multiple wireless communication protocols simultaneously, including ZigBee and Bluetooth it was used a wireless microcontroller type nRF52840 from Nordic Semiconductor.

This microcontroller is a multi-protocol device. It supports the following protocols: Bluetooth, Thread, ZigBee, 802.15.4 and others. The microcontroller is based on a 32-bit floating-point ARM Cortex-M4 processor with a clock speed of 64 MHz. It has digital peripherals and interfaces such as SPI and QSPI for connection to external flash memory and monitor, USB port for data transfer, as well as a built-in charger for battery charging.

The introduction of the Bluetooth protocol in wireless remote monitors makes it possible to use them not only as part of the clinical network via the ZigBee protocol, but also offline. The user can control the monitor and receive data from it via mobile phone or tablet using Bluetooth.

Thus, remote medical monitoring systems with artificial intellect elements, such as wireless medical smart sensors, smart injectors, as well as wearable medical monitors in general, are already the subject of engineering developments, and practical application, what cannot be said about remote centers of diagnosis.

Remote diagnosis outside the clinic is a requirement of today. In a pandemic, patients have significant limitations in hospital care. Communication with a family doctor is usually done remotely. To support patients in such circumstances, we offer special medical communicators with a built-in expert system.

Such IT communicator was developed in the V.M. Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine and in Shupyk

National Medical Academy of Postgraduate Education. Developed IT communicator is based on the mobile tablet computer with special application-dependent software and at first it was intended for the following purposes [Romanov et al, 2016]:

1. In medicine, including emergency medical aid: for supporting first contact of doctors with patients (with voice limitation), and getting information about patient state. In this case, the IT communicators help such patients to communicate with doctors. Particularly it is important for family doctors who often are the firsts to examine patients.

2. In family medicine: to support doctors, especially family doctors, during patient examination and diagnosing. In such case, if the family doctor hasn't enough experience and knowledge to diagnose in correct way, he can use digital databases with detailed formalized information about a large number of traumas or diseases and proper methods of medical treatment or care.

3. In education: during continuous professional development of doctors and pharmacist.

4. In prediagnosis: for estimating quality of life.

As it was mentioned, IT communicator makes it possible communication between doctors and patients with move and voice limitation. Figure 6 shows the main menu of the smart communicator and the window, where patient can locate the place of pain to help doctor. There are following Menu items: "Needs", "Requests", "Pain", "Emergency aid", and "Keyboard". By using this menu and submenus the patient with voice limitation can ask peoples around or doctor for help, service or medicaments, or explain own feelings, troubles or pain. It is possible to convert written by patient needs to voice. It is necessary to add that IT communicator stores the patient medical history.

The second subsystem of smart communicator is intended to support family doctors and simplify the communication between doctor and patient. To remove some problem in communication between doctor and patient it is reasonable to computerize the formalized and standard models and situations in communication, what usually lets to avoid the effect of incorrect understanding of certain "message" both data sender and data recipient. Smart communicators are reasonable to be used by family doctors to get detailed information about trauma or disease and proper methods of medical treatment or care during first examination of sick or injured person. For family medicine, it is described more than 500 standardized situations, which include as cases of emergency medical aid, so planed activity of medical care. The window with details of illness or injury, for example the asthma and window with visual explanation are shown in Figure 7. In addition, proposed communicator subsystem contains databases with reference information, what helps to avoid a lot of traumas or diseases.

Figure 6. Main menu and pain location windows

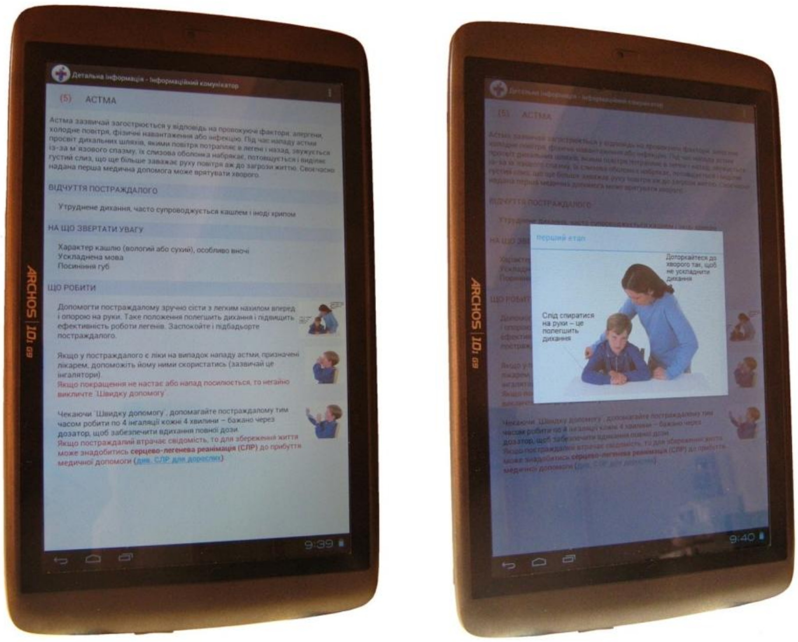

Figure 7. Detailed information about trauma or disease (with visual explanation)

The third subsystem is intended for continuous professional development of doctors and pharmacist.

The fourth subsystem is intended for estimating of quality of life (QOL). Assessing the adequate level of health of patients and the effectiveness of treatment methods require modern clinical studies of "quality of life" using various standardized questionnaires, both general purpose and designed for individual nosologies. The assessment of QOL, which is performed by the patient using questionnaires, together with the traditional medical opinion of the doctor, gives a complete and objective description of the patient's condition.

The goal of the fourth subsystem is to automate quality of the life assessment based on the standardized MOS SF-36 questionnaire using smart communicator with application software as information support for making objective medical decisions. In the table 1 you can see Content-based Descriptions of Lowest and Highest Scale Scores of MOS SF-36 [Ware et al, 1993].

Table 1. Content-based Descriptions of Lowest and Highest Scale Scores of MOS SF-36

Concepts	Meaning of Scores	
	Lowest Possible	Highest Possible
Physical Functioning (PF)	Limited a lot in performing all physical activities including bathing or dressing due to health	Performs all types of physical activities including the most vigorous without limitations due to health
Role-Physical (RF)	Problems with work or other daily activities as a result of physical health	No problems with work or other daily activities as a result of physical health
Bodily Pain (BP)	Very severe and extremely limiting pain	No pain or limitations due to pain
General Health (GH)	Evaluates personal health as poor and believes it is likely to get worse	Evaluates personal health as excellent
Vitality (VT)	Feels tired and worn out all of the time	Feels full of pep and energy all of the time
Social Functioning (SF)	Extreme and frequent interference with normal social activities due to physical or emotional problems	Performs normal social activities without interference due to physical or emotional problems
Role-Emotional (RE)	Problems with work or other daily activities as a result of emotional problems	No problems with work or other daily activities as a result of emotional problems
Mental Health (MH)	Feelings of nervousness and depression all of the time	Feels peaceful, happy, and calm all of the time

The method of estimating the quality of life according to the MOS SF-36 questionnaire is based on the instruction for calculating the indicators of quality of life, for which the application software has been developed. This application software estimates quality of life indicators on 8 scales. To develop application software for proposed medical communicator there were used Java programming language and integrated environment Android Studio 3.6.3, which provides storage of survey data and calculating the indicators of quality of life on recommended scales. An appropriate database has been created. The structure of the medical diagnostic expert system, based on questionnaires for different purposes is shown in Figure 8.

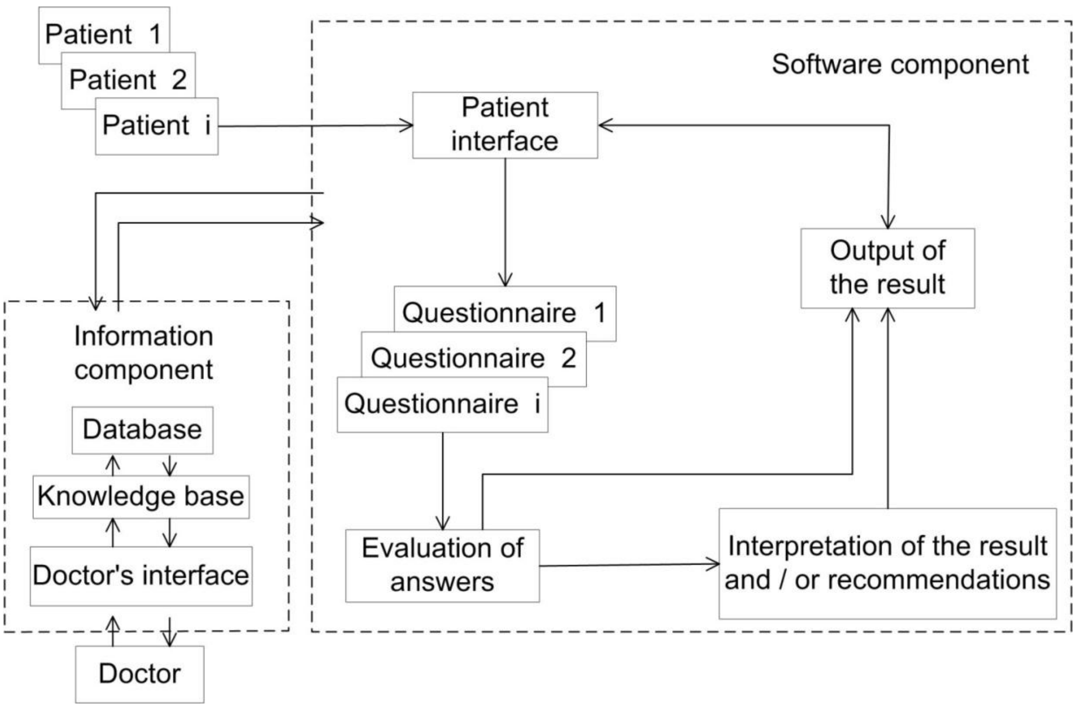

Figure 8. Developed medical diagnostic expert system structure

The components of the system are following:

- "Patient";
- "Doctor";
- "Software component";
- "Information component".

Entity–Relationship Model of Database for storage patient's answers was developed too.

The results of the survey are presented on histogram, which contains eight scales PF, RP, BP, GH, VT, SF, RE, MH and two summary scales PCS, MCS, Figure 9.

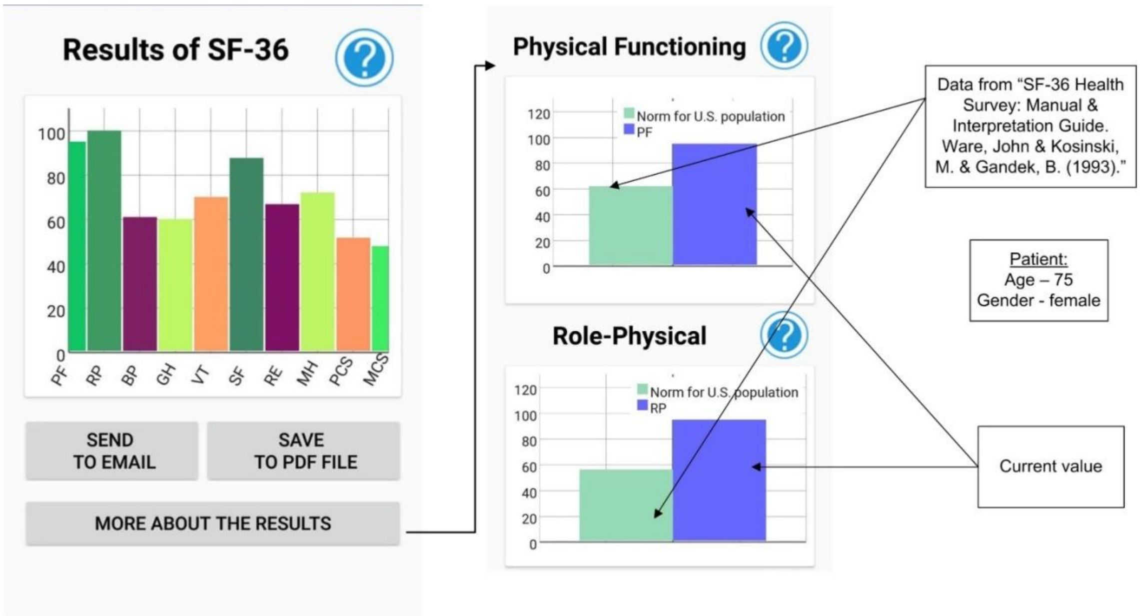

Figure 9. Histogram with eight scales PF, RP, BP, GH, VT, SF, RE, MH and two summary scales PCS, MCS

The "More about the results" button is intended for a more detailed view of the survey results. The results of data processing include 10 separate histograms for each SF-36 questionnaire scale and two summary scales. On the left column of the Figure 9 it is shown the norm values of US patients [Ware et al, 1993, Ware and Kosinski, 1993]. Right column includes the current example of patient's values. Given example is for women, age 75. The analysis of the subject area of common standardized questionnaires to assess the quality of life of patients revealed the optimal for automation - The 36-Item Short Form Health Survey - a short form of non-specific questionnaire for quality of life. The stage of development of software for automation of quality of life assessment based on the standardized questionnaire MOS SF-36 for smart communicator has been completed. The results of the issue can serve as information support for making informed medical decisions with developed expert system.

Conclusion

Microelectronic components for new wireless wearable medical monitors intended for chronically ill patients, but also for post-corona pandemic people, and people who are actively involved in sports or undergo heavy physical or psychological stress in the performance of their professional duties were analyzed. It was discussed the medical IT communicator, developed in the V.M. Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine and in Shupyk National Medical Academy of Postgraduate Education and intended for the emergency medical aid, family medicine, and estimating quality of life.

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Authors' Information

Volodymyr Romanov *– Head of department of V.M.Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine, Doctor of engineering sciences, professor; Prospect Akademika Glushkova 40, Kyiv, 03187, Ukraine; e-mail: VRomanov@i.ua; website: http://www.dasd.com.ua*

Igor Galelyuka *– Leading research fellow of V.M.Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine; Candidate of engineering sciences; Prospect Akademika Glushkova 40, Kyiv, 03187, Ukraine; e-mail: galelyuka@gmail.com; website: http://www.dasd.com.ua*

Oleksandr Voronenko *– Research fellow of V.M.Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine; Prospect Akademika Glushkova 40, Kyiv, 03187, Ukraine; e-mail: alexander.voronenko@dci.kiev.ua; website: http://www.dasd.com.ua*

Oleksandra Kovyrova *– Research fellow of V.M.Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine; Prospect Akademika Glushkova 40, Kyiv, 03187, Ukraine; e-mail: kovyrova.oleksandra@gmail.com; website: http://www.dasd.com.ua*

Ozar Mintser *– Head of department of P.L. Shupyk National Healthcare University of Ukraine, Doctor of technical sciences, professor;.Dorogozhytska str., 9, Kiev, 04112, Ukraine; e-mail: o.mintser@gmail.com*

Tetiana Pyatchanina *– Head of the Research and Innovation Management Department of Kavetsky Institute of Experimental Pathology, Oncology and Radiobiology of National Academy of Sciences of Ukraine; Vasylkivska str, 45, Kyiv, 03022, Ukraine; e-mail: tanya_pyatchanina@ukr.net; website: https://iepor.org.ua/en/*