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HEALTH MONITORING BY FUNCTIONAL INDICATORS WITH THE HELP OF SENSORS AT THE PHASE OF PATIENT REHABILITATION IN TODAY'S CONDITIONS

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Abstract. Nowadays, people's need for fast and effective rehabilitation processes is growing significantly. Sensory devices are available for people with functional disabilities, which are used for rehabilitation to help a person's health and return to an appropriate standard of living. Scientists in the field of rehabilitation medicine are actively studying the method of remote monitoring of the physiological indicators of the human body. The last decade has been marked by the intensive development of research in the field of sensor devices. For example, mechanical, robotic systems and exoskeletons, which enable people with limited physical capabilities to move their bodies, occupy an important place among the technical means for restoring the condition of the human locomotor system. Despite the existence of various technical systems and means for rehabilitation after injuries and diseases of the spine and lower limbs, the latest modern exoskeletons of various types have not yet been used.

When analyzing the literature, it is indicated that the sensor sensors are attached to the devices that make it possible to measure the functional indicators of the state of human health. Sensory technologies in rehabilitation continue to develop comprehensively and are often used for diagnosis, assessment of human health and rehabilitation. The given analysis of rehabilitation exoskeletons provides a basis for the conclusion that their use will increase the effectiveness of assistance to paralyzed patients after a stroke, brain injuries, spinal cord injuries, in the presence of limitation of the functions of the musculoskeletal system during treatment and in the hospital and post-hospital rehabilitation period.

Keywords: Sensors, rehabilitation, health monitoring, exoskeleton.

Introduction. For today the health of the population of Ukraine is not only a problem of a socio-economic and medical nature, but also a factor which affects the stability of the economy against internal and external threats. Medical technologies in Ukraine and in other countries of the world progressing very quickly, so nowadays during the war with russia, people's need for fast and effective rehabilitation processes is growing significantly after injuries and operations, sensory impairments, strokes, accidents, brain injuries, Parkinson's disease, psychological disorders, sports injuries and, finally, for the elderly [1, 2, 3]. A complete recovery process can be achieved with a daily frequency of procedures from several days to months, and sometimes years, depending entirely on the patient's health and desire for a speedy recovery (Mohammaddan and Komeda, 2010) [4]. To follow this progression, users need knowledge about rehabilitation tools that can help in the rapid recovery of the patient. A sensor is a measuring device in the form of a constructive set of one or more measuring transducers, which is measured and controlled, and which produces the output signal, convenient for remote transmission, storage and use in control systems and has standardized metrological characteristics. Sensors (in medicine and rehabilitation) - special technical devices that transform one physical phenomenon into another in equivalent quantities. In rehabilitation medicine sensors are more often used, that convert mechanical displacement, light intensity, temperature and other physical quantities into electrical signals [5, 6].

All sensors are based on the design and principle of input signal conversion in electric are divided into dynamic and static. Piezoelectric and electrodynamic sensors are widely used among dynamic sensors. Piezoelectric sensors used to register various processes, related to movement and vibration of body parts (pneumography, pulsography, mechanocardiography, sphygmography). A thermocouple is also a dynamic sensor, which is used to measure the temperature of organs and tissues. Electrodynamic sensors used to register various movements of body parts (ballistocardiography, dynamocardiography). Physiological sensors is one of the fundamental parts for signal processing and for an automated rehabilitation system [1, 4, 6].

The last decade has been marked by the intensive development of research in the field of sensor devices.

For example, mechanical, robotic systems and exoskeletons, which enable people with limited physical capabilities to move their bodies, occupy an important place among the technical means for restoring the condition of the human locomotor system [6, 7]. Despite the existence of various technical systems and means for rehabilitation after injuries and diseases of the spine and lower limbs, the latest modern exoskeletons of various types have not yet been used.

The purpose of the study: To conduct an analysis the latest literary sources regarding the types of sensors in the rehabilitation of patients in today's conditions.

Materials and methods.

The bibliographic method is used in the research and analytical methods in the following electronic databases: Science Direct, PubMed, Scopus and Google Scholar.

Abstracts were analyzed during article search. Inclusion criteria were: (1) physical and medical rehabilitation and/or assistive system supported by sensors and computer, (2) systems designed for the human body, and (3) documents written in English. If the expected criterion was found, the full text was reviewed.

Research results and their discussion. General discussion, new inventions and aspects of the development of new sensory systems used in the rehabilitation process in hospital and after the hospital period. Stefania B, Sara C, Ilaria P, Barbara L. (2010) [8] proposed a system of mechanotronic neurorehabilitation. This system can assess functional recovery after stroke by measuring whole body isometric strength. Prange, G.B., Jannink, M.J.A., Groothuis-Oudshoorn, C.G.M., Hermens, H.J., Ijzerman, M.J. (2006) [9] та Karatas, M., Cetin, N., Bayramoglu, M., Dilek, A., (2004) [10] justify why the rehabilitation process is fundamental to restoration of motor skills after a stroke. Scientists in rehabilitation paid special attention to the examination of the functional state of a person after a stroke by measuring the patient's isometric strength and electrocardiography. Stefania B, Sara C, Ilaria P, Barbara L. (2010) [8], Prange, G.B., Jannink, M.J.A., Groothuis-Oudshoorn, C.G.M., Hermens, H.J., Ijzerman, M.J. (2006) [9] та Karatas, M., Cetin, N., Bayramoglu, M., Dilek, A., (2004) [10] focused on some limited sensors, their application in physical recovery systems and compared with each other.

Pantelopoulos A., Bourbakis N. (2008) [11] studied the application of portable and wearable sensors for health monitoring systems. Katherine MT, Holly AY, David J, Feil-Seifer Maja JM. (2008) [12] reviewed robotic assistive technology in clinical aspects and human-robot interaction for medical and physical rehabilitation, but they did not clearly mention the names of the sensors. Janis and Jonathan, (2008) [13] analyzed signal processing methods and algorithms between brain and computer interface for neurological rehabilitation system.

In the literature available to us, not a single previously published work was found, where the authors would generalize the combination of sensors with hardware, robotic, computer systems for the rehabilitation of patients of different age categories.

The wide range of studies included and reflected in this review involved different types of sensors. Researchers have mainly used electromechanical, electrical, optical, and thermal sensors, acoustic signal transducers, or mass-sensitive sensors to develop rehabilitation systems. Some of the most commonly used sensors that have been used in rehabilitation systems are electromyography, galvanic reaction of the skin, electrocardiography, electroencephalography, units of measurement of inertia [1, 14-17]. Majdalawieh O, Gu J, Bai T, Cheng G (2003) [15] explained the relationship between biomedical signal and rehabilitation engineering with electromyography, electroencephalography. In fig. 1 presents a graphic representation of the registration of electroencephalography signals of a child's brain [1, 15, 18].

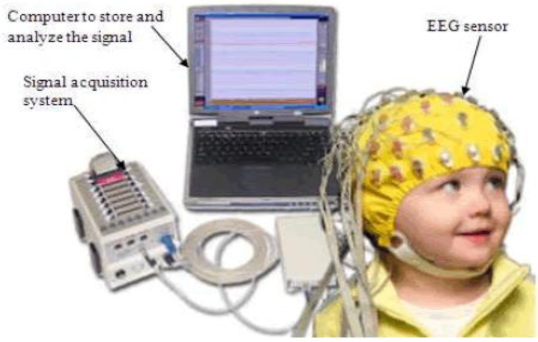

Fig. 1 Registration of electroencephalography signals of children's brain [1, 18].

In many publications [12, 14, 15, 16, 19] the authors emphasize the monitoring of electroencephalography signals in medical institutions. Electroencephalography is a diagnostic procedure to assess the condition of muscles, nerves, and the nerve cells that control them. When performing this study, peripheral nerves are stimulated with short-term electrical impulses. The technique is non-invasive, as electrodes placed on the skin are used. Needle electroencephalography is more often used when there is suspicion of motoneuron diseases (spinal amyotrophy, amyotrophic lateral sclerosis, etc.) and muscles themselves (myopathy, inflammatory diseases, etc.). At the same time, a thin needle electrode is inserted into the muscle, which registers the activity of the muscles at rest and during contraction. Electromyography makes it possible to confirm a clinical diagnosis, to monitor the course and treatment of the disease, as well as to provide rehabilitation services.

Kozyavkina O. V., Kozyavkina N. V., Hordiyevych M. S. та інші (2018) [3], Enzo Pasquale, S., Gemignani, A., Paradiso R., Taccini, N. (2005) [2] та Ahamed, NU., Sundaraj, K., Poo, TS. (2013) [20] analyzed existing methods of rehabilitation where doctors and rehabilitators use traditional and innovative methods and technologies, rehabilitation massage, technologies and means of information-wave therapy and hardware methods to increase the effectiveness of rehabilitation measures.

Having studied and analyzed the literature, it can be stated that that scientists, in the field of medical, biological and technical sciences, there are many developed and described computer systems used in rehabilitation medicine. In these systems, researchers have specified different types of hardware and software information, which are used as the main elements and communication bridges for rehabilitation technology. Common computer programs used in rehabilitation systems include: MatLab, LabVIEW and Virtual Reality [1, 21, 22].

Stanley Colcombe and Arthur F. Kramer (2003) [23] indicate that that physical activity directly affects the level of physical and psychological health of a person, and also on emotional well-being. With the need to plan and organize physical activity, the issue of monitoring the performed physical activity arises [1, 24, 25].

Today, sensor devices used to monitor physical activity are divided into: 1) sensors that measure such biological indicators as pressure, heart rate, breathing rate - heart rate monitor, tonometer, spirometer; 2) motion sensors – pedometers, accelerometers, activity trackers [1, 5, 6]. The sensors in the rehabilitation system, composed of flexible and stretchable materials, have the potential to interact better with human skin, while the silicon-based electronics are extremely efficient in processing and transmitting data to the sensors. Flexible medical devices designed to monitor vital human functions such as body temperature, heart rate, respiratory rate, blood pressure and blood glucose. Health monitoring dachas are used for medical diagnosis [1, 25].

Scientists in the field of rehabilitation medicine are actively studying the method of remote monitoring of the physiological indicators of the human body. The rehabilitator attaches a device or devices to the patient, on which sensors with autonomous power are placed, which register physiological indicators and indicators of position in space. After the actions, the rehabilitator turns on his mobile device and begins to receive indicators in real time from sensor sensors, which are displayed on the monitor in the form of graphs and charts. The rehabilitator can monitor the functional state of the patient directly during the therapeutic exercises and after their completion [1, 6, 9, 22].

In fig. 2 a patient monitoring system is shown that can work remotely, for example, in geriatric centers or hospitals. One or more mesh devices are provided in this system «Mesh Network Appliances 8» to provide wireless communication in the home monitoring system. «Mesh Network Appliances 8» mesh network can be one of several portable physiological transducers, such as blood pressure monitor, heart rate monitor, thermometer, spirometer, single or multi-channel electrocardiograph [4, 15, 18].

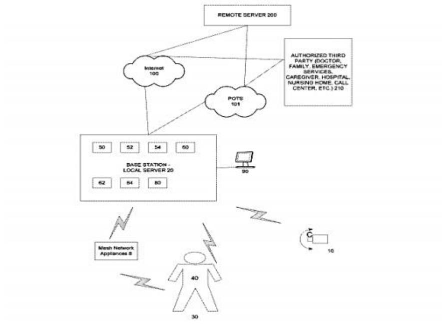

Fig. 2. Patient monitoring system [18].

As an example, a typical algorithm of devices for monitoring the functional state of human health is considered. The device worn by the patient includes one or two-way wireless communication line (Fig. 2), for data transmission from «Mesh Network Appliances 8» to a local hub or receiving station or BASE SAON - LOCA. SERVER 20 by wireless radio frequency communication using the protocol. For example, a user may have mesh network devices within the home. In this case, a sick person can have access to an alarm transmitter. Other sensors and/or detectors can also be included. The user can register these devices in the central security network, by entering the identification code for each registered device and/or systems. Monitoring cameras are placed in the premises "10" which can be placed at various predetermined points in the patient's home "30". Base station / server 20 stores a picture of the patient's placement and his vital signs. Base station / server 20 is available to the patient's family members, doctors, rehabilitators and nurses. Patient "30" may wear one or more monitoring devices. A device worn or used by the patient, for example, such as wristwatches, devices for measuring ECG, blood pressure, sugar level, includes touch sensors "40". The sensors include standard medical diagnostics to detect the body's electrical signals emanating from the muscles, brain and cardiovascular system. Sensors used on the lower limbs may include piezoelectric accelerometers designed to provide qualitative assessment of limb movement. A small touch sensor can be placed on the patient's finger to detect heart rate. Each of the sensors "40" can individually transmit data to the server "20" using wired or wireless transmission [1, 18, 26].

Tsvyakh A, Hospodarskyy A. (2017) [26] investigated telemedicine technologies in the rehabilitation of patients with injuries of the lower extremities. Home remote monitoring of patients included the use of a smartphone with a gyroscope, a G-sensor, a magnetometer and a barometer, which was attached to the injured lower limb.

Mazzoleni, S., Van Vaerenbergh, J., Toth, A., Munih, M., Guglielmelli, E. and Dario, P. (2005) [27] described the ALLADIN diagnostic device with sensors, which consists of several components: a modular platform where the patient is equipped with eight Force / Torque sensors that receive data while performing a simulated «activities of daily life»; database, which is used to store all received data; a computer operator interface that will be used by a physical therapist / rehabilitator.

As an example, the ALLADIN diagnostic device (Fig. 3.) is presented, which includes nine components and is used in neurorehabilitation to assess post-stroke functional recovery. The device includes a database in which all functional indicators and other clinical indicators of the patient are stored [1, 27].

Fig. 3. Components of the ALLADIN diagnostic device: 1- Board for storing accessories, 2 - Wheelchair, 3 - Patient monitor, 4 - Podium, 5 - Trunk device, 6 - Leg device, 7 - Device lever, 8 - Hand device , 9 – Seat [27].

The use of a diagnostic device together with brain imaging systems (for example, functional magnetic resonance imaging), brain activity monitoring techniques - electroencephalography, and physical activity monitoring will allow monitoring the degree of functional changes at various stages of rehabilitation [1, 15, 27].

New technologies of components, sensors, microcomputers, new materials are used in real-time integrated control of some very complex dynamic systems - humanoid robots that have up to 50 degrees of freedom and are controlled by a controller in microseconds.

One of the most famous medical devices is a robotic suit - an exoskeleton, which allows people with limited physical abilities to move their bodies (Yu. Popadyukha (2016)) [7]. These are some of the popular exoskeletons today (Yu. Popadyukha (2016)) [7]: Walking Assist Device – assistive device for walking (Honda, Japan); rehabilitation HAL (Cyberdyne, Japan) - widely used in hospitals; the Indego exoskeleton (Parker Hannifin, Vanderbilt University) makes it possible to move the hip and knee joints; powerful NASA X1 for paralyzed people; Kickstart (Cadence Biomedical) uses the kinetic energy generated by a person when walking; eLEGS (Ekso Bionics); rehabilitation REX (Rex Bionics, New Zealand); ReWalk (ARGO, Space Applications Services) exoskeletons that help paralyzed people; unique brain-machine interface (BMI) - MAHI-EXOII brain exoskeleton to restore motor functions by reading brain waves.

Consider some of the exoskeletons listed above (Yu. Popadyukha (2016)) [7]:

1. Exoskeleton Mindwalker фірми Space Applications Services (Belgium) will help paralyzed people to walk again [7]. Experts are testing a kind of controlled exoskeleton robot that would enable completely paralyzed people to walk. The Mindwalker project uses electrodes easily attached to a person's head that can read brain signals related to movement, which can be translated into commands for the exoskeleton to operate. The robotic suit, which attaches to a person's legs, is designed to more closely mimic how humans walk compared to other exoskeletons that require additional walking devices in the form of sticks to support the person (Fig. 4).

Fig. 4. General view of the Mindwalker exoskeleton (Yu. Popadyukha (2016)) [7].

The exoskeleton is designed to explore promising approaches for using brain signals to control new prostheses. Mindwalker will find application in the rehabilitation of patients after a stroke, providing assistance to astronauts to restore muscle mass after long periods of stay in orbit. A neuro-machine interface was developed that converts electroencephalography signals from the brain, received from the shoulder muscles, into electronic commands for controlling the exoskeleton. Neural machine interface signals must be filtered and processed before they can be used to control the exoskeleton.

Space Applications Services has developed a virtual reality training platform. Space Applications Services enables new users to safely get used to using the exoskeleton before testing it in clinical conditions.

The UniExo exoskeleton [7] helps people with limited physical abilities (paralyzed limbs) to move. The exoskeleton is controlled using a neurohelmet or neurobracelets (Fig. 5). The exoskeleton includes sensors, servos, controllers and software that can be configured in 5 minutes according to the patient's characteristics. The UniExo design consists of robotic elements, servomotors, sensors and a software control unit. It is through the C or NXT control unit that the exoskeleton is programmed for a specific rehabilitation program.

Fig. 5. The author with the Ukrainian sample of the UniExo exoskeleton (Yu. Popadyukha (2016)) [7].

SIPPC robotic exoskeleton crawler [7] will help children at risk of cerebral palsy. The SIPPC (Self-Initiated Prone Progression Crawler) device is designed to develop the brain and improve the motor skills of children during the critical period of development (2-8 months). The device helps the baby to improve his motor and cognitive skills. Rehabilitators claim that at this age, correction of cerebral palsy symptoms is most effective, as intensive development of the motor system and related cognitive processes takes place. The SIPPC robotic exoskeleton is a soft pad for a child that moves with the help of three wheels. A set of 12 motion sensors and a set of cameras continuously record movements during crawling in three dimensions (Fig. 6). At the same time, a helmet with electrodes is placed on the baby's head, which record the activity of the corresponding areas of the brain. The information is then sent to the computer, a machine learning algorithm analyzes the child's movements and helps them perform them, giving positive feedback and strengthening motor skills.

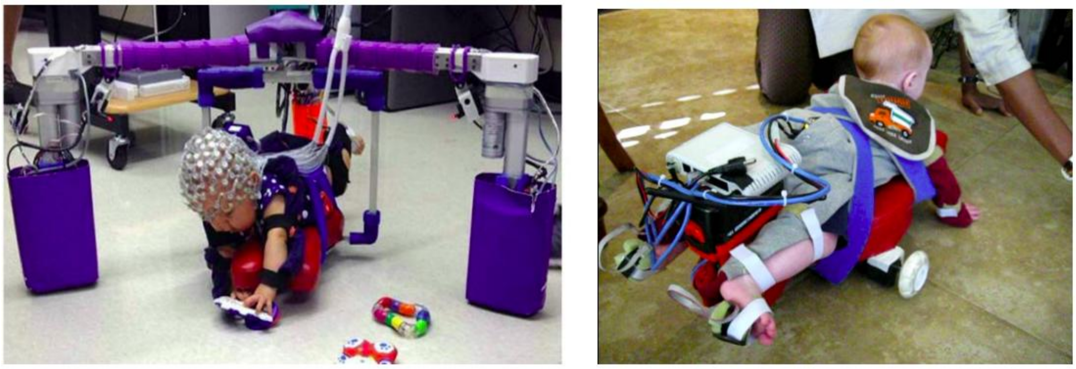

Fig. 6. SIPPC robotic exoskeleton for a baby (Yu. Popadyukha (2016)) [7].

Thus, the analysis of modern foreign literature on the types of sensors and their use in rehabilitation measures indicates that they are indeed present and constantly used in the rehabilitation process.

Conclusion. When analyzing the literature, it is indicated that the sensor sensors are attached to the devices that make it possible to measure the functional indicators of the state of human health. Sensory technologies in rehabilitation continue to develop comprehensively and are often used for diagnosis, assessment of human health and rehabilitation. The given analysis of rehabilitation exoskeletons provides a basis for the conclusion that their use will increase the effectiveness of assistance to paralyzed patients after a stroke, brain injuries, spinal cord injuries, in the presence of limitation of the functions of the musculoskeletal system during treatment and in the hospital and post-hospital rehabilitation period.

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