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REVIEWS, LECTURES

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MODERN CAPABILITIES OF TELEBIOMETRIC MONITORING STUDIES OF THE FUNCTIONAL STATE OF THE ORGANISM OF THE HUMAN

REVIEW

PART II. SENSORY SYSTEMS

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Introduction. The sensory aspect of the telebiometric multimodal model (TMM sensory layer) is considered in the scientific literature as an identifier of human sensations that cause or manifest incoming or outgoing influences when a person interacts with the environment. Of particular importance in this sense is the study of the functional state of the body of persons employed in risky industries, where the establishment of a causal relationship between the influence of the working environment and the state of health of workers has the highest socio-economic cost. In addition, research in this direction may be relevant for assessing the functional state of the body of the military, rescuers, firefighters and other professions where there is a need for remote monitoring of critical physiological indicators in order to prevent dangerous biomedical consequences.

The aim of the study is a review of monitoring systems, such as «smart vests», helmet-mounted sensor systems, eye-tracking, systems on a skin-conformal platform, which can be used to study the physiological state of workers in hazardous occupations.

Materials and methods of research. Information search was carried out in the Internet search engines and specialized electronic databases: google.com, Scholar, PubMed, Mendeley, eLIBRARY.

Results. The presented review contains subsections: «Smart vests» – in which sensors can be embedded to record various physiological parameters; Helmet-mounted sensor systems – where real-time monitoring of concussion and cognitive changes is considered; Skin-conformal platforms are very thin sensor systems superimposed on the surface of the skin to measure temperature, sweat composition, electrical characteristics, etc.; eye-tracking systems – eye movement monitoring. The possibilities of 3D printing for individualization of measurement conditions are also mentioned.

Conclusions. It has been established that the improvement of methods for monitoring the functional state of the body of persons employed in risky professions is possible with the introduction into medical practice of remote methods for measuring physiological data using telecommunication systems, among them: states; to assess the neurocognitive state, stimulate and control behavior during training and physiological testing – «smart glasses» (eye-tracking systems); to control individual indicators, such as temperature measurement, intensity and composition of sweating – skin-conformal sensors.

Key words: telebiometrics, smart vests, eye-tracking, skin-conforming platforms, monitoring

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Introduction

This work is a continuation of the literature review [1] on the current capabilities of monitoring systems for human physiological indicators that can be classified as «smart clothing». The process of remote recognition of biometric data using telecommunication systems is the basis of telebiometrics as a concept. The sensory aspect of the telebiometric multimodal model (TMM sensory layer) is considered in the scientific literature [2] as an identifier of human sensations that cause or detect input or output influences during human interaction with the environment. Of particular importance in this sense is the study of the functional state of the body of persons engaged in hazardous industries, where the establishment of a causal link between the impact of the production environment and the health of workers has the greatest socio-economic value. Research in this area may be relevant for assessing the functional state of the body of military personnel, rescuers, firefighters and other professions where there is a need for remote monitoring of critical physiological parameters in order to prevent dangerous biomedical consequences.

The current state of development of methodological approaches to the implementation of telebiometry and sensor networks technologies for monitoring the medical and biological indicators of the functional state of the body (FSB) of persons engaged in risky areas of production and non-production activities can be defined as a stage of revolutionary changes and disruption of existing paradigms in information technology. This is especially true for the information security of telebiometry systems and sensor networks. For example, the most well-known wireless protocol of Bluetooth technology does not meet the appropriate information security due to the openness of the system and its vulnerability to external interference. Another class of technologies based on the principle of communication organisation, Ad-Hoc networks, are distinguished by dynamic self-organisation and multi-hop routing, and are designed for decentralised, dynamic, distributed applications. These technologies have been a priority area of scientific information search because they, among other things, provide a higher level of data collection, monitoring and analysis using sensor networks, telebiometry in the public health system; communication in emergency situations (rescue, emergency, anti-terrorist operations); organisation of operational communication between different types of telebiometric devices; communication networks between moving vehicles, etc.

One of the main technologies designed to create wireless personal area networks (WPANs) is ZigBee (6LoWPAN), which is based on standards developed by the IEEE 802.15 working group. This standard is specifically designed for use in medical diagnostic devices, medical equipment and biosensors.

NASA's Technology Transfer Program [3], called NASA SPINOFF, is a programme that has transferred space technologies that benefit life on Earth in the form of commercial products. Since 1976, more than 2,000 spin-offs have been transferred under this programme. For example, the Ames Research Centre offers health monitoring software that studies system behaviour based on data, namely Inductive Monitoring System (IMS), Version 5 (reference number ARC-15058-1A). The IMS software uses techniques from the fields of reasoning modelling, machine learning and data mining to create system monitoring knowledge bases from archived or simulated sensor data. The technology automatically analyses nominal system data to generate general classes of expected system

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sensor values. These classes are used to build the monitoring knowledge base. When monitoring a system, IMS simply checks to see how well the incoming sensor data fits into the classes derived from the training data. IMS includes the Outlier Detection Via Estimating Clusters (ODVEC) software, which provides an efficient method for analysing multi-factor sensor data in real-time or offline for use in detecting anomalies, faults, and monitoring system performance. ODVEC software uses models automatically derived from archived system data.

The aim of the study is to review the scientific literature on monitoring sensor systems such as smart vests, helmet-mounted sensor systems, i-tracking systems, skin-conformal platform systems that can be used to study the physiological state of the body of people engaged in risky occupations.

Materials and methods of research

The information search was carried out in Internet search engines and specialised electronic databases: google.com, Scholar (https://scholar.google.com), PubMed (https://pubmed.ncbi.nlm.nih.gov), Mendeley (https://www.mendeley.com), eLIBRARY (https://elibrary.ru).

Results of research and their discussion

«Smart vests»

Today, smart vests are already a broad class of smart clothing. These products are used not only for the purpose of monitoring human FSB, but also in industry, ensuring more functional and safer work for employees. Relevant technical solutions include: ELOshield's «smart vest» (in particular, for warehouse workers), which provides an emergency signal of the need for help, has an individual user tag, light and sound elements, vibrating elements to generate signals of tactile events, and a gas analyser [4]; Biped.ai vest, which allows visually impaired people to avoid collisions [5], where the technology can be extended to conditions with limited visibility. A product with the commercial name ProeTEX has been developed for rescuers [6, 7]. The main elements of the product are an inner vest with sensors for monitoring physiological parameters (sensors for monitoring heart rate, respiration, body temperature, blood saturation (SpO_2), motion and bending sensors), and an outer vest with sensors for monitoring environmental parameters such as air temperature and carbon monoxide (CO) concentration, an alarm system and data visualisation. An important element of ProeTEX is the ability to quickly access the medical and physiological data of a user who is in a dangerous condition as a result of injury, collapse, loss of consciousness and other reasons. There are attempts to develop systems similar to ProeTEX for law enforcement officers [8]. Increased interest in «smart» technologies is also manifested in the study of the functional state of the military [9, 10]. The main tasks in monitoring research among the military can be reduced to: monitoring health and functional status; monitoring environmental conditions; stress management; expanding human functionality; studying the effectiveness and compliance with the physiological characteristics of equipment.

There are a number of detailed and implemented developments of monitoring systems with appropriate software. For example, the Modular Biotelemetry System for Military Applications (FlexiGuard) is worthy of note [11]. Studies [12, 13] describe the automation of monitoring of special forces by parallel monitoring of each member of

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the special team separately, including the collection of physiological parameters such as body temperature, heart rate, acceleration, and skin moisture.

According to the number of test participants, smart things (clothing, vests) are classified into individual devices, mixed-type devices, and group (or team) devices [14]. The latter allow tracking the movement of the test object in relation to others. This is also effective in providing group measurements of physiological parameters in real time, as in this case, data transmission technology based on a wireless decentralised Ad-Hoc network can be used. If the person (e.g., commander, doctor) who makes decisions about the physiological state of a person is in close proximity to the events where the team is located, i.e., the observer actually participates in the tests, then wrist computers (wrist PCs) are promising technical solutions for monitoring the state of the group. These are portable devices whose functionality is largely similar to conventional desktop computers with the appropriate operating systems. In commercial and practical terms, these computer systems are currently the most commonly used for monitoring the FSB and external conditions when working underwater.

One of the tasks of assessing the FSB of people undergoing intensive training or are in unfavourable conditions for health is to assess the heat balance by indicators of internal body temperature – core temperature [15, 16]. Usually, the methodology for assessing core temperature is carried out by measuring the temperature at points on the body determined by the methodology. At the time of this writing, no commercial smart clothing products have been found that have a set of temperature sensors for measurements using this method. In addition, depending on the clothing of the person being monitored, the temperature readings at certain points may have different weighting factors. Therefore, appropriate methods for assessing core body temperature need to be refined, calibrated and validated. To solve this problem, the company (https://www.hqinc.net/) has developed the CorTemp Sensor pill to use it per os. This pill passes wirelessly through the digestive tract and transmits a signal at 262 kHz or 300 kHz about the internal temperature profile at specific parts of the digestive tract. The sensor signal goes through the body to the CorTemp data logger, which is worn on the body. Examples of scientific and practical applications of the corresponding system are given in [16, 17].

With a sufficiently large working surface, smart vests allow sensors to be placed in different parts of the body and an electrocardiogram to be obtained using 12 leads [18]; using multiple sensors (optical), it is possible to monitor respiratory parameters [19].

Commercial products that are leading the market include the following smart vests: BioShirt, ProeTEX, GOW system, HeartCycle's guided exercise system, Hexoskin and Astroskin, Long Term Medical Survey System, Maglietta Interattiva Computerizzata, CardioLeaf (Clearbridge VitalSigns, Singapore) and hWear (HealthWatch Technologies, Kfar Saba, Israel), Protection e-Textiles (inner garment), LifeShirt, Wealthy system, Wearable Wellness System, Zephyr BioHarnes [20]. In different variations, these products measure: respiratory parameters, heart rate, temperature, blood saturation, energy losses. It should be noted that the undisputed leader in scientific and practical validation of research results based on publications is Hexoskin (Carr Technologies Inc.) with its Hexoskin and Astroskin products – more than 100 references were found. Among these models of «smart vests», they are the most versa-

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tile in terms of physiological parameters which are monitored.

Sensor systems on the helmet

The location of sensor measurement systems can be the human head, especially in cases where a protective helmet is an integral element of equipment. For example, the research [21] investigates the capabilities of a corresponding system for measuring electroencephalography on four channels and SpO_2. A more advanced similar system, which can assess the degree of head injury or blast wave impact based on the use of pressure (impact sensors) and acceleration (accelerometer) sensors, is presented in [22]. In a more general case, a review paper [23] is devoted to the monitoring of moderate brain injuries.

Skin conformal platforms

The so-called biomarkers, measured by low- or non-invasive sensors, biosensors, provide high selective information about the physical state of a person. It is of some interest to monitor and measure in real time analytes of the aqueous phase from monoatomic ions, small molecules (e.g., steroid hormones and metabolites) to proteins (e.g., cytokines and chemokines). This is due to the fact that neurotransmitters and hormones (both steroid-based and protein-based) are usually considered because of their ability to control and modulate physiological functions [24]. To evaluate these biomarkers, skin temperature and electrical conductivity are measured on the skin surface, elasticity is assessed (e.g., by the indentation method), photoplethysmography is used, sweat rate is assessed, and biochemical selective sensing is performed [25]. Modern technologies for monitoring these characteristics involve the use of thin «stamps» or plasters that are directly applied to the skin – Skin-Conformal Platforms or Electronic-skin. Information about a number of representative studies using flexible, elastic, ultrathin nanoscale platforms is given in review papers [26, 27]. A more specific example of one of these Chem-Phys sensors with a manufacturing technique is given in [28]. A fairly effective technology for manufacturing sensors for measuring electrolytes in sweat and pH, which can be mastered in many laboratories using conductive threads and a medical patch, is presented in [26]. The authors present a hybrid sensor system worn on the skin that provides simultaneous real-time monitoring of biochemical (lactate) and electrophysiological (electrocardiogram) signals. The main disadvantage of many Skin-Conformal Platforms, which hinders the widespread adoption of most of these systems, is the single-use nature of the brand with a rather high price of the sensor.

Unfortunately, no review papers on the analysis and comparison of commercial offers related to the use of Skin-Conformal Platforms technologies were found. On the market, the Gx Sweat Patch and Sweat sticker for assessing sweat rate and sodium loss should be highlighted as relatively widely available. According to the analysis of the global market [29] (Electronic Skin Patch Market), the main players in this area are: Vital Connect Inc., Leaf Healthcare Inc., Quad Industries, L'Or al SA, Sensium Healthcare Ltd; according to [32], the companies: MC10, Physical Optics Corporation, Dialog Semiconductor, Intelesens Ltd., 3M, Koninklijke Philips N.V., Plastic Electronics GmbH, ROTEX Global, SmartLifeinc Limited, VivaLNK, Xenoma, Xsensio, GE Healthcare; Tapecon Inc.

Skin-conformal platforms have been more widely used for temperature sensors [30, 31]. Commercially available systems include: Kenzen

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Patch; Gamastech, Microlife PT 200 BT, Thesyspharma KD-3110, etc. (see https://www.medicalexpo.com); Verily Patch [32] and many others.

In our opinion, monitoring studies have great prospects not only for measuring the average temperature values from the skin surface, but also for the dynamics of its spatially heterogeneous distribution and the formation of thermal patterns. Indoors, thermography methods using high-resolution infrared thermal imagers are the most suitable for such analysis [33]. The clinical and theoretical significance of spatial temperature heterogeneity, in particular for the treatment of tumours, was discussed in [34]. Flexible temperature sensor array/matrix can be used to study these processes when using smart clothing. The analysis of temperature fluctuations can also be of high diagnostic value, in particular for non-invasive glucose measurement [35].

Eye movement monitoring (i-tracking)

Another type of monitoring system is Eye tracking, or analysis of the eye movement trajectory [36]. In clinical settings, related techniques are called oculography. The essence of the technique is to track and subsequently analyse the trajectory of the eye. In monitoring studies, two video cameras are aimed at the respondent's eyes, while the third camera is aimed at the object under study. This allows to capture both eye movements and the object in question. The respondent does not have to sit still. This technology is used in neurocognitive research, stimulation and control of human behaviour while driving a vehicle, attention control (including latent attention), sports training, analysis of points of interest (in an image, for example, in marketing research or training), remote control of computer systems by people with disabilities, etc. [37, 38].

Eye tracking devices vary greatly in their hardware implementation. Some of them are mounted on the surface of the face (registering the activity of the eye muscle), some require the patient's head to be fixed, some are something like lenses that are directly applied to the eyeball (2D and 3D inductive sensors), and others operate remotely (e.g., special glasses, webcams, etc.) [39, 40]. Most systems operate at a shooting speed of at least 30 frames per second. Although the most commonly used frame rate is 50/60 frames per second, 12, 300, 500, or even 1000/1250 frames per second are also used [41]. In some tasks, such as general attention when studying educational material, it is not necessary to track and analyse eye movements, and the registration of blink rates [42], which is provided by household video recording devices, is sufficiently informative.

The following are examples of commercial systems for monitoring studies outside specialised clinical facilities, which are mainly represented by glasses with cameras: Gazepoint GP3 Desktop Eye-Tracking system, Tobii Pro Glasses 2, Pupil Labseye-tracker, HTC Vive VR headset and LooxidVR headset [43]; a system that is placed on a table and has the ability to connect EEG, etc. sensors – EyeLink 1000 Plus [44]; Applied Science Laboratories (ASL) EYE-TRAC 6 desk-mount model, ASL Mobile Eye Tracker, SMI eye tracking system, Tobii-T120, Tobii 1.0 eye-tracking glasses, Tobii 1750 Eye Tracker device [45].

3D printing

Today, 3D printing plays a special role in the manufacture of smart clothing, reliable attachment of sensors to the body surface, and individualisation of the shape of the worn elements [46–48]. This is

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especially relevant in clinical settings when treating patients and adapting measurement systems to equipment that did not originally have built-in sensors. In addition, commercial offers include conductive materials for 3D printing, which allows for the direct printing of individual sensors. In this sense, customisation simultaneously addresses hygiene aspects without significantly affecting the price of the product.

In general, if a sensor system requires a clear link to the geometric features of the human body, it is necessary to use specialised 3D laser scanners or 3D medical images from magnetic resonance and/or computed tomography. This necessitates the use of specialised software tools for image processing and analysis, primarily for their segmentation and subsequent construction of a 3D computer model. The use of high-tech equipment and software requires the involvement of engineers with experience in the field of medicine and technology in the development of the relevant products.

Conclusions

It has been established that the improvement of methods for monitoring the functional state of the body of persons engaged in hazardous professions is possible with the introduction into medical practice of remote methods of measuring physiological data using telecommunication systems, including: helmet sensors for the prevention and assessment of the degree of head concussion during the performance of official duties and assessment of the psycho-emotional state; for assessing the neurocognitive state, stimulation and control of behaviour during training and physiological testing – «smart glasses» (i-tracking systems); skin-conformal sensors are used to monitor individual indicators, such as temperature, sweat intensity and composition.

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