ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2006. Nr. 7(71)
ELEKTRONIKA IR ELEKTROTECHNIKA

MEDICINE TECHNOLOGY
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MEDICINOS TECHNOLOGIJA

Measurement of Human Physiological Parameters in the Systems of Active Clothing and Wearable Technologies

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Introduction

Fast development of electronics, radio communication systems and also textile industry enables modern technologies to be employed for the safety secure at workplaces to save life and health of workers. Various systems of wearable technologies and active clothing, which integrate electronic and control components into textile materials or worker's wearable equipment, are being developed to this end [1]. The main aim of those systems – enable human physiological parameters to be registered and analyzed continuously during his work activities. Proper evaluation of those parameters would let us immediately know about sudden health state changes, accidental injury or another menacing danger befalling worker at workplace.

Recent efforts to design active clothing systems and thence reached results reveal a great potential of those systems as well as wide employment possibilities [1-5]. Despite this outlook, it's still rather new field of application and most of prototypes of the system are still under investigation stage.

In this work we analyze the physiological parameters applicable for human health state indication as well as their registration methods and means. We also make a survey of individual long-term health state monitoring systems design, based on wearable technologies and active clothing appliance.

Physiological parameters reflecting health state

Generally, human health state is defined by variety of physiological parameters, which usually are self-interdependent. Not all of them are equally informative and important. Besides, not all of those parameters could be easily and precisely controlled, since measurement of them requires special conditions, expensive medical equipment and materials. While designing the overall monitoring system, it is necessary to assess not only importance of measured parameters but also techniques of their measurement and potentiality of implication into practical systems.

Medical investigations have proven that the most important parameters are those that specify the work of heart and respiratory system. They best describe the human heath state. In addition to this, body's temperature is also an important parameter. Basic metrical parameters of human health evaluation and physiological parameters defined by them are presented in Table 1.

Table 1. Basic human physiological parameters

The measured parameter	The analyzed physiological parameters	The character of the measured signal
1. ECG	Variation of electrical heart vector, heart work rate	Time function, mean numerical value
2. Pulse	Heart work rate	Mean numerical value
3. Respiratory rate	Respiratory rate	Numerical value
4. Respiratory volume	Minutely respiratory volume gauge	mean numerical value
5. Body temperature	Temperature	Numerical value
6. Blood pressure	Systolic and diastolic blood pressure, heart rate	Time function, numerical value

Cardiovascular system parameters

It is always advisable to register heart work related parameters when evaluating human health condition, since the heart work is associated with physiological functions of vital importance to the human body.

The prime heart work related physiological parameters are heart work rate (pulse) and blood pressure. Practically they could be obtained in several ways, which are detailed next.

Electrocardiogram (ECG) is one of the most representative characteristics of heart work [6]. ECG represents heart's electrical activity recorded from electrodes on the body surface.

The sinus node in the heart is one of the cardiac conduction system elements that control the heart rate. It generates electrical impulses and conducts them throughout the muscle of the heart, stimulating the heart to pump blood. The electrical signal generated by the sinus node moves from cell to cell down through the heart and so induced and not induced spatial areas in heart are created. It is possible to describe the electric generator of the heart reasonably accurately with an equivalent dipole, called the *electric heart vector*. It has proper direction and size, which turns and changes according to hearth work rhythm. ECG may be regarded as projection of the electric heart vector on the respective lead vectors as a function of time.

Figure 1 represents typical ECG. The deflections in the signal are caused by heart's depolarization and repolarization cycles. The biggest peak in the signal represents so-called "ventricular" depolarization, which begins from the outer side of the ventricles and then the electrical repolarization front "propagates" inward.

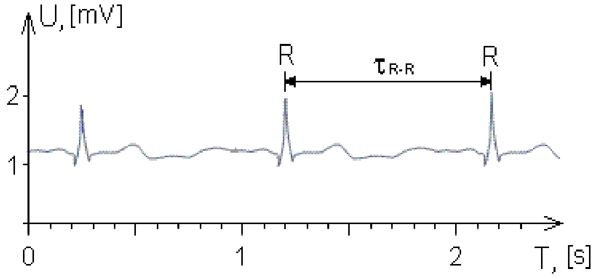


Fig. 1. Typical ECG

Pulse, as heart work rhythm characterizing parameter, can be easily calculated from ECG. This might be done by measuring distance between the biggest peaks (usually named R peaks). After a few cycles of heartbeat recorded, the duration of R-R step is measured and pulse is calculated:

$$pulse = \frac{60}{\tau_{R-R}} \left[\min^{-1}\right].$$

The amplitude, shape and waves of ECG signal depend on ECG lead system and derivations used. Two arrangements of ECG electrodes – bipolar and unipolar – are available for heart electricity registration during its depolarization and repolarization. Bipolar is one in which the electrical activity at one electrode is compared with that of another. By convention, a positive electrode is one in which the ECG records a positive (upward) deflection when the electrical impulse flows toward it and a negative (downward) deflection when it flows away from it. In unipolar arrangement the electrical potential at an exploring electrode is compared to a reference point that averages electrical activity, rather than to that of another electrode. This single electrode, termed the *exploring electrode*, is the positive electrode.

Despite the fact that most of physiological examinations of human health state nowadays include ECG measurements, telemetric ECG signals acquisition especially meanwhile patient's physical activity is still rather complicated task. In exercise ECG, the signal is distorted because of muscular activity, respiration, and electrode artifacts due to perspiration and electrode movements. This requires additional signal conditioning means.

When measuring ECG in the worker's active clothing systems for protective and warning purposes usually it is enough to evaluate pulse, which is one of the most important physiological parameters.

Along with ECG, some other non-invasive blood pulse measurement methods are available also. One of them is photo–plethysmography. According to this method, the pulse is defined by arterial blood oxygenate, measuring light absorption by blood. When light passes through body tissues, it is absorbed in different amounts by bones, vessels, body fluids, skin and venous or arterial blood. Blood pulse sensors uses light emitters, which are arranged to emit infrared light, having a wavelength of about 940nm. This wavelength is within the absorption spectrum of the hydroxyl constituents of arterial blood. Light detectors are applied to measure change in backscatter, which indicates change of absorption, which in turn indicates change of flow volume. In this way, the occurrence of blood pulse is detected.

Sensors may be applied to the subject's finger, wrist, neck or ear lobe. For precise measurement it is indispensable to separate recurrently pulsing signal of the blood and signal of other body tissues absorption. The extraneous interference signal may occur due to the changes of shape and position of body's tissues during exercises and body movements. By its nature this method is more prone to the movement artifacts than ECG technique.

Another method to measure pulse is impedance plethysmography. This is a method of determining changing tissue volumes in body, based on the measurement of electrical impedance at the body surface [8]. Pulsing change of blood amount in different parts of body, caused by systemic blood circulation within cardiovascular system, causes proportional changes of electrical impedance. The impedance is found by introducing an electric current in the frequency range of 20 –100 kHz to the volume conductor and measuring the corresponding voltage. The ratio of voltage to current gives impedance Z.

To eliminate the effect of electrodes, separate electrode pairs for introducing the current and for measuring the voltage should be used. An example of placement of four band electrodes is shown in fig. 2. In particular arrangement of the outer pair, one electrode is placed around abdomen and the other around the neck. For the inner pair, one electrode is placed around the breast, ant the other around the neck. In recent studies of impedance cardiography, the band electrodes are often replaced with normal ECG electrodes.

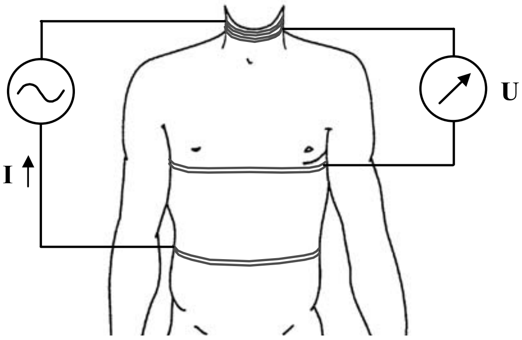


Fig. 2. Placement of electrodes using impedance plethysmography technique

The main disadvantage of this method – relatively high consumption of energy, which is one of the most important factors in mobile technologies. Another objectionable thing in this method is passing of electricity through human body. This might result in significant interference effect, finding due the cardiac, muscular or electrode artifacts.

Blood pressure is the second physiological parameter describing heart's work. In the central arteries of adult people the average value of blood pressure stays practically constant during whole their life, but in some periods it may straggly change under the sway of various factors, for example, under influence of psychical and physical stress, breathing and ambient temperature change. The accurate information about momentary and average blood pressure values may be achieved by direct intra-arterial blood pressure measurement, which can be done both during human quiescence and active state. However, this technique is not practical, and founds its application mainly within clinician investigations.

The indirect auscultatory (Korotkoff) method of blood pressure measurement is commonly used today [8]. With this method the pressure is determined by use of measure device, called sphygmomanometer. The cuff used in this case is inflated to a level above arterial pressure. Then the cuff is gradually deflated, ant the pressure is noted at which sounds produced by arterial pulse waves (Korotkoff sounds) appear and disappear again as flow through the artery resumes. Indirect measurement auscultatory method is sufficiently accurate for medical diagnostic purposes.

However, most automatic instruments used for blood pressure measurement, uses oscillometric method. This is more indirect method, and instruments are usually empirically calibrated against the auscultatory method. Automatic instruments work on the principle that when the artery does open during a portion of the pressure cycle, a tiny perturbation, or oscillation, will be superimposed on the pressure inside the cuff. The cuff used there may be wrapped around the wrist (sometimes – finger). The amplitude of those oscillometric signals waxes and vanes over the curse of the deflation of the cuff. The systolic and diastolic blood pressures are defined from varying signal amplitude profile, which actually never goes fully to zero that makes practical evaluation of the pressure to be a fuzzy problem.

Indirect methods of blood pressure measurement usually requires the patient not to be physically active during measurement procedure, otherwise it brings a significant errors into measurements. Besides indirect measurements could not be done continuously for a long time. It only could be repeated at certain time intervals.

All this points out, that today's possibilities to use blood pressure measurements within active clothing systems are rather limited.

Respiratory system parameters

Respiratory ensures permeation of the oxygen into the human body. Special medical equipment is required to register respiratory characteristics, so called respiratory system parameters. Those parameters featuring human health state consequently can be divided into three groups:

- volume parameters;
- respiratory system physical parameters (respiratory rate and other mechanical parameters of respiratory system);
- parameters of gas metathesis within the lungs.

Volume parameters (total lungs capacity, tidal breath, functional remaining capacity and others) characterize potential and functionality of human body parts that respond for respiratory functions. Physical parameters are related to mechanical model of respiratory system. Respiratory rate is one of those parameters. Gas metathesis parameters are related to gas penetration into human body and exhausting from it when breathing. All those parameters are interdependent and measurement of some of those parameters gives us possibility to calculate the rest of them.

Both conventional and remote measurement of respiratory system parameters traditionally uses respiratory masks, which are not much compatible with telemetric principles of measurement. Recent trials to perform precise measurement of respiratory system parameters using alternative mask-free measurement methods adduced ambiguous results. Indirect mask-free methods evaluate respiratory parameters according some other physical body parameters, like recurrent impedance of human body tissues and others. The main problem is the accuracy of the results, since most of known methods are sensitive to human body movements and that introduces significant errors into respiratory parameters measurements.

Impedance pneumography and inductive plethysmography are two the most promising noninvasive technologies available now for measuring respiratory function [9,10].

Impedance pneumography employs low amplitude, high frequency (50-500 kHz) alternating current between two surface electrodes to record thoracic movements or volume changes at the rib cage during respiratory cycle.

Several limitations inherent to the impedance pneumography technology can lead to errors in respiratory measurement. First, the electrical resistance of rib cage tissues is less than of air, therefore current passing across the thoracic cavity reflects mainly tissue impedance. Thus, while this method can provide a qualitative indication of chest wall movement, there is no direct relationship to thoracic volume. Further, the electrodes attached to the skin record impedance off all tissue types through which the electrical current travels, including muscles. The method is therefore more prone to motion artifacts. Cardiogenic artifact is another source of recording error inherent in impedance pneumography.

Inductive plethysmography is newer alternative to impedance pneumography, associated with a higher degree of accuracy and has additional benefits to practical application. The technique employs sensors to measure changes in a cross-sectional area of the rib cage and abdominal compartments during a respiratory and cardiac cycle. The sensors consist of arrays of sinusoidally arranged conductive wires excited by a low current, high frequency (~300kHz) electrical oscillator circuit (Fig. 3).

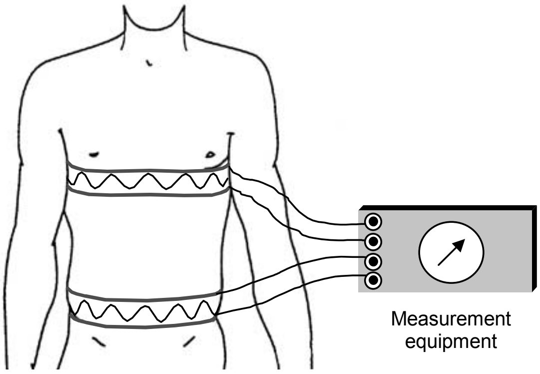


Fig. 3. Placement of respiratory band sensors

Movement of rib cage and abdominal compartments cause the sensors to generate magnetic fields, which are measured as voltage changes over time. No electricity passes through the monitored individual.

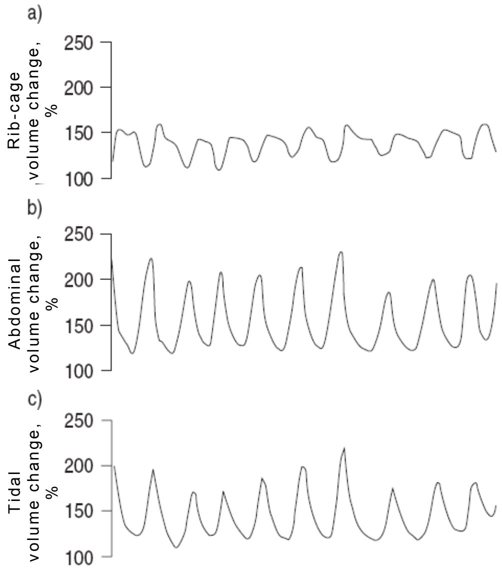


Fig. 4. Respiration respective signals: a) rib-cage area; b) abdominal area; c) tidal signal

Fig. 4 represents waveforms of volume change taken from rib cage and abdomen arias, and tidal volume representing the sum of rib cage and abdominal signals. Most of respiratory parameters are evaluated from tidal volume waveform.

Inductive plethysmography method is associated with less signal interference and distortion in compare with impedance pneumography. Besides, inductive plethysmography includes bands placed over the abdomen in addition to the rib cage, allowing more precise measurement.

On the other hand all non-invasive methods only can support partial information about area changes during breathing. They can't substitute traditional invasive methods when precise measurements of respiratory volume parameters or parameters of gas metathesis in the lungs is needed. Those methods are usually applicable where only qualitative indication of respiratory function is adequate.

Body temperature

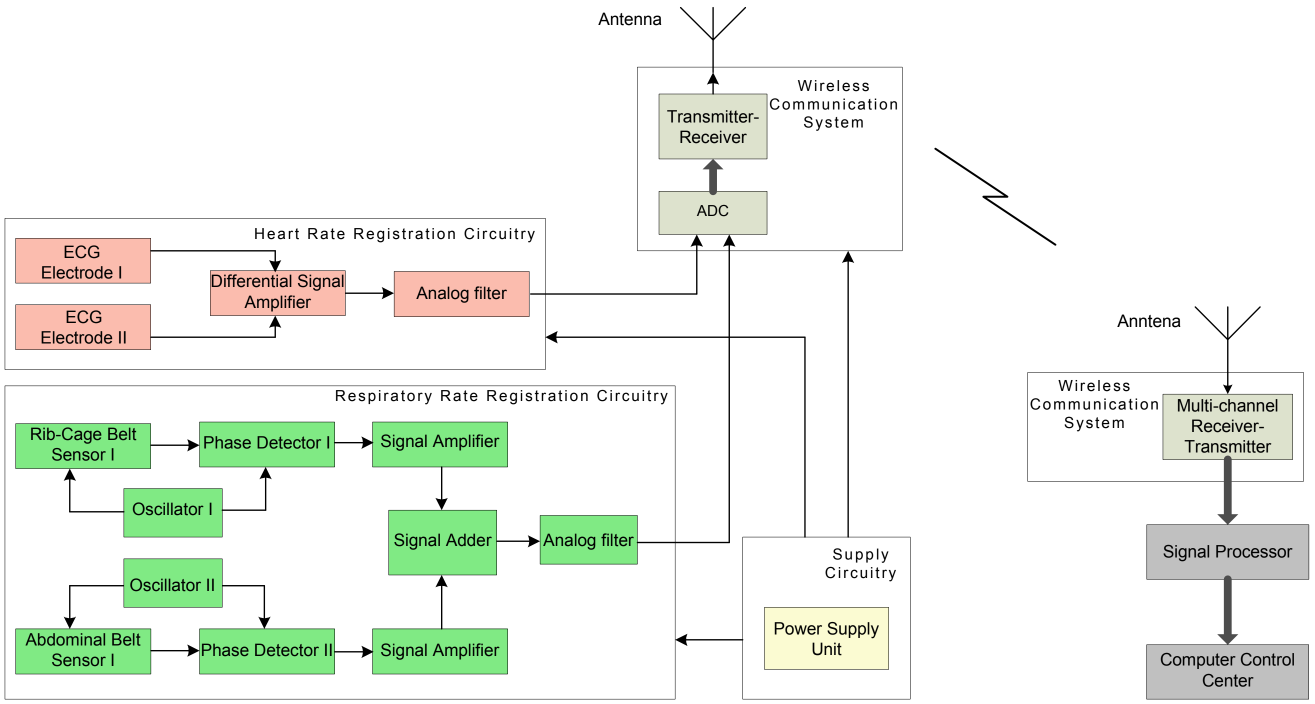
In a healthy individual, body temperature is kept constant in a very small range despite of big differences in temperature of the surroundings and also those in physical activity. This is achieved by systemic nervous regulation. Nervous system maintains the optimal intensity of metabolism and at the same time regulates the amount of heat loss. Overall human body temperature is rather different, especially within inner and outer parts of the body. Temperature measured in anus is about 37.1ºC, in mouth – 36.7ºC, in armpit – 36.5ºC. For a healthy person this temperature is almost invariable and depending on person may deviate only ±0.4ºC. Body temperature changes are more intensive in young person than in old people. The temperature may slightly or temporarily increase in hot environment. Physical activity may also increase the body temperature. In extreme effort, the increase may be very high. The temperature in marathon runners may increase to 39ºC or 41ºC. The temperature may increase slightly if vasodilatation, hyperventilation, and other compensation mechanisms fail.

Telemetric measurements of human body temperature usually employ electronic temperature sensors such like thermo-couple or thermo-resistor. Such sensors allow measurement to be done fast (about 1.5 min), and whole measurement procedure is well established. However, body's temperature is not such important physiological parameter by itself, like cardiovascular and respiratory system related physiological parameters. It provides additional information about human health state.

Wearable individual security system

The individual health state monitoring system based on wearable technologies and active clothing, generally constitutes of two parts:

- mobile part – part of the system attached to the observed individual. It embraces sensors, signal registration and transmission circuitry, supply unit and other components;



(a) (b)

Fig. 5. Block diagram of health control system: a) mobile part that person wears; b) stationary part that receives and process information

- stationary part – part of the system, which is remote from the observed individual. It possesses signal processors and transmitters and is directly connected with overall system control center.

The exact possession of components in mobile and stationary parts of the system depends on purpose and peculiarities of each individual health control system.

The highest efficiency of the system is achieved when real time collection, transmission and proceeding of registered data is performed. Besides optimization of the received information amount and purport is indispensable, to preserve the overall system of becoming too complicated and slow.

According to principles stated above, the feasible system of the prime diagnosis of health disorder was proposed, including registration of two basic human physiological parameters – pulse and respiratory rate. The block diagram of the system is presented in Fig. 5.

In the physical arrangement of the mobile part, the sensors, signal preprocessing devices, supply units and transmitters are settled on two stretchy belts fastened around bosom and abdomen areas of observed person. Steady cables connect those two belts. Components on belts are situated close each to other, to avoid noises in electrical circuits. Radio wave range is used to perform connection between mobile and stationary parts. The distance of transmission may vary from 50 meters to several kilometers.

Figure 6 illustrates arrangement of wearable equipment on the human body. Workers of extreme occupation, like guards, dispatchers, high-rise builders and others, might use such individual wearable health control system. The proposed system might be extended, to measure more human parameters, like body temperature, blood pressure and others.

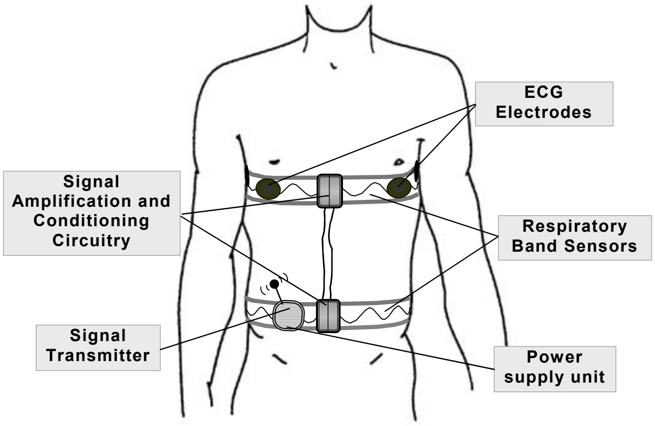


Fig. 6. Arrangement of wearable equipment representing a mobile part of health state monitoring system

Conclusions

Pulse and respiratory rate are two primary physiological parameters that should be always controlled using active clothing ant wearable technologies systems for worker's health state control and accidents preventive purposes at work. Body temperature might be used as additional parameter for health state estimation.

The physiological parameters monitoring system proposed, enables registering of pulse and respiratory rate of workers and sending physiological data to remote center, where his health state is evaluated.

Though the mobile part of the system is proposed to realize as wearable equipment, still there is possibility to integrate it to active clothing. There is also possibility to extend the proposed system, to measure more human physiological and environmental parameters.

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Submitted for publication 2006 04 07

A. Dosinas, M. Vaitkūnas, J. Daunoras. Measurement of Human Physiological Parameters in the Systems of Active Clothing and Wearable Technologies // Electronics and Electrical Engineering. – Kaunas: Technologija, 2006. – No. 7(71). – P. 77–82.

Various systems of wearable technologies and active clothing, which integrate electronic and control system components into textile materials or human wearable equipment, are examined in this work. Application of those systems for worker's safety secure at workplaces is considered. Physiological parameters that describe human health state are being registered and analyzed to this end, using diagnostic means integrated into worker's clothing. The major physiological parameters are reviewed and their registration methods and means are analysed in this work. The key attention is paid to potentiality of mobile and practical measurement means, which allow a long-term registering of forehead chosen physiological parameters, creation. According to analysis results achieved, the real-time health state monitoring system was proposed, including registration of two basic human physiological parameters and thus providing advanced diagnosis of health disorders. The schematic of feasible realisation of monitoring system, implemented as wearable technology was proposed in the work too. Ill. 6, bibl. 10 (in English; summaries in English, Russian and Lithuanian.).

А. Досинас, М. Вайткунас, И. Даунорас. Измерение физиологических параметров человека в системах активной одежды и носимых технологий // Электроника и электротехника. – Каунас: Технология, 2006. – № 7(71). – С. 77–82.

В статье анализируются системы активной одежды и носимых технологий, интегрирующие элементы электроники и систем управления в текстиль и специальные носимые принадлежности, рассматривается применение этих систем для обеспечения безопосности отдельно работающих работников. С этой целью физиологические параметры, определяющие состояние здоровья человека, регистрируются и оцениваются при помощи диагностических средств, интегрированных в рабочей одежде. В работе рассмотрены основные физиологические параметры, анализируются методы и средства их измерения. Основное внимание уделено возможностям разработки мобильных практических средств измерения, позволяющих длительное время непрерывно регистрировать выбранные физиологические параметры. По результатам анализа предложена действующая в рельном времени система контроля здоровья работников, контролирующая два основных физиологических параметра и позволяющая диагнозировать первичные признаки расстройства здоровья. Предложена одна из возможных практических реализаций такой системы на основе носимых технологий. Ил. 6, библ. 10 (на английском языке; рефераты на английском, русском и литовском яз.).

A. Dosinas, M. Vaitkūnas, J. Daunoras. Žmogaus fiziologinių parametrų matavimas aktyviosios aprangos ir dėvimųjų technologijų sistemose // Elektronika ir elektrotechnika. - Kaunas: Technologija, 2006. – Nr. 7(71). – P. 77–82.

Darbe nagrinėjamos dėvimųjų technologijų ir aktyviosios aprangos sistemos, integruojančios elektronikos ir valdymo sistemų elementus į tekstilę arba žmogaus dėvimus daiktus, aptariamas šių sistemų taikymas pavieniui dirbančių darbuotojų saugai darbe užtikrinti. Šiam tikslui yra registruojami ir vertinami sveikatos būklę nusakantys žmogaus fiziologiniai parametrai, panaudojant diagnostines priemones, integruotas darbinėje aprangoje. Apžvelgiami minėtieji fiziologiniai parametrai, analizuojami jų matavimo metodai ir priemonės. Daugiausia dėmesio skiriama mobilių matavimo priemonių, leidžiančių nepertraukiamai ilgą laiką registruoti pasirinktuosius fiziologinius parametrus, sukūrimo galimybėms. Atsižvelgiant į analizės rezultatus, darbe pasiūlyta realiu laiku veikianti darbuotojų sveikatos kontrolės sistema, kontroliuojanti du svarbiausius fiziologinius parametrus ir kartu leidžianti diagnozuoti pirminius sveikatos sutrikimo požymius. Pasiūlyta viena iš galimų tokios sistemos praktinio taikymo dėvimųjų technologijų pagrindu schemų. Il. 6, bibl. 10 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

DOI: 10.5755/j02.eie.10778