https://doi.org/10.32603/1993-8985-2019-22-3-122-129

Nguyen Mau Thach[1] ✉, Nguyen Trong Tuyen[1], Tran Trong Huu[2]

[1]Le Quy Don Technical University
236 Hoang Quoc Viet, Hanoi, Vietnam

[2]Vietnam Military Medical University
160 Phung Hung, Hanoi, Vietnam

METHOD AND SYSTEM FOR ASSESSING OF A SPORTSMAN'S PHYSIOLOGICAL RESERVES DURING PHYSICAL EXERCISES

Abstract

Introduction. *An assessment of the sportsman's physiological reserve (PR) and its dynamics, is important when planning and carrying out training and forecasting of a sportsman's results. One important point of this problem is the increase in high-performance sports and energy consumption sports. A complexity of solving this problem is caused by the requirement of taking into account the complex world of the biomedical parameters and the formation of an integral parameter. This parameter reflects the functioning of the various body systems which provide significant income to the sportsman's results and achievement.*

Objective. *Development of the method and the system of PR assessing allowing complex investigation of the PR during the training process.*

Method and materials. *For achievement of the aim the tasks were formulated and solved using methods of biomedical research and engineering, mathematical processing and analysis of the diagnostically valuable parameters.*

Results. *The complexity of the biomedical parameters reflecting a sportsman's body metabolism in conjunction with physical exercise are formed. These are: the heart rate, the heart rate variability, the pulse frequency, the systolic and diastolic pressure. Also, the respiratory rate, the blood saturation, and the stress index by Baevsky. It is important for the PR assessment to assess the parameters characterising a sportsman's physiological reserves in the current moment and its dynamics. The circle diagram is proposed for taking into account of all the mentioned parameters and its variation dynamics. The value of the integral PR parameter is an area of a polygon, which is obtained on the circle diagram using normalized values of the diagnostically significant parameters. The method of biomedical investigation of a sportsman and the method of PR assessment are based on the complex of the body system parameters which are developed. The scheme of assessing a sportsman's body physiological reserves before and after training are proposed. The scheme allows the assessment of not only a sportsman's body energy consumption during training, but also its recovery after their training. General structures of the biotechnical system and a structure of systems of picking up, registration, processing and analysis of biomedical signals for the assessment of a sportsman's physiological reserves are developed. Special attention is given to the development of a wearable device for synchronous registration of the complex parameters and algorithms of the assessment of the diagnostically significant parameters of a sportsman's body"s physiological reserves.*

Conclusion. *The proposed method of a sportsman's physiological reserves investigation and the structure of the system with spatially distributed architecture, allow sport"s medicine doctors and coaches to assess the efficiency of a sportsman's training process with respect to their potential capabilities and efficiently control the training process.*

Key words: method, system, assessment, sportsman's physiological reserves, statistic and dynamic parameters, recovery of physiological and functional reserves

For citation: Nguyen Mau Thach, Nguyen Trong Tuyen, Tran Trong Huu. Method and System for Assessing of Sportsman's Physiological Reserves during Physical Exercises. Journal of the Russian Universities. Radioelectronics. 2019, vol. 22, no. 3, pp. 122–129. doi: 10.32603/1993-8985-2019-22-3-122-129

Acknowledgements. Initiative work.

Conflict of interest. Authors declare no conflict of interest.

Submitted 19.04.2019; accepted 20.05.2019; published online 27.06.2019

Nguyen Mau Thach[1] ✉, Nguyen Trong Tuyen[1], Tran Trong Huu[2]

Le Quy Don Technical University
236 Hoang Quoc Viet, Hanoi, Vietnam

Vietnam Military Medical University
160 Phung Hung, Hanoi, Vietnam

МЕТОД И СИСТЕМА ОЦЕНКИ ФИЗИОЛОГИЧЕСКИХ РЕЗЕРВОВ СПОРТСМЕНА ВО ВРЕМЯ ТРЕНИРОВОК

Аннотация

Введение. *Оценка физиологического резерва (ФР) спортсмена и его динамики актуальна при планировании и проведении тренировок, прогнозировании результатов спортсмена. Актуальность данной проблемы усиливается в спорте высоких достижений, в частности в энергетически затратных видах спорта. Сложность решения этой проблемы обусловлена необходимостью учета комплекса медико-биологических показателей и формирования интегрального показателя, отражающего функционирование различных систем организма, которые обеспечивают значимый вклад в достижение результата спортсмена.*

Цель работы. *Разработка метода и системы оценки ФР, позволяющих комплексно изучить ФР во время тренировочного процесса.*

Методы и материалы. *Для достижения поставленной цели были сформулированы и решены задачи с использованием методов медико-биологических исследований, биомедицинской инженерии, математической обработки и анализа диагностически значимых показателей.*

Результаты. *Сформирован комплекс медико-биологических показателей организма, отражающих метаболизм организма спортсмена в условиях физических нагрузок. Это частота сердечных сокращений, вариабельность сердечного ритма, частота пульса, систолическое и диастолическое давление, частота дыхания, сатурации крови, индекс напряженности Баевского. Для оценки ФР важно оценивать показатели, характеризующие физиологические резервы спортсмена в текущий момент времени и их динамику. Предложена круговая диаграмма для комплексного учета всех перечисленных показателей и динамики их изменения. Количественной мерой интегрального показателя ФР является площадь многогранника, полученного на круговой диаграмме по нормированным значениям диагностически значимых показателей. Разработан метод проведения медико-биологических исследований спортсмена и метод оценки ФР на основе комплекса показателей систем организма, предложена схема оценки физиологических резервов организма спортсмена до и после тренировок. Она позволяет оценить не только энергозатраты организма спортсмена во время тренировок, но и его восстановление после тренировок. Разработана обобщенная структура биотехнической системы и структуры системы съёма, регистрации, обработки и анализа биомедицинских сигналов для оценки физиологических резервов спортсмена. Особое внимание уделено разработке носимого устройства для синхронной регистрации комплекса биомедицинских сигналов и алгоритмам оценки диагностически значимых показателей физиологических резервов организма спортсмена.*

Заключение. *Предложенный метод исследования физиологических резервов спортсмена и структура системы с пространственно-распределенной архитектурой позволяют тренеру и врачу спортивной медицины оценивать эффективность тренировочного процесса спортсмена с учетом его потенциальных возможностей, эффективно управлять тренировочным процессом.*

Ключевые слова: метод, система, оценка, физиологический резерв спортсмена, статические и динамические показатели, восстановление физиологического и функционального резерва

Для цитирования: Nguyen Mau Thach, Nguyen Trong Tuyen, Tran Trong Huu. Метод и система оценки физиологических резервов спортсмена во время тренировок // Изв. вузов России. Радиоэлектроника. 2019. Т. 22, № 3. С. 122–129. doi: 10.32603/1993-8985-2019-22-3-122-129

Источник финансирования. Инициативная работа.

Конфликт интересов. Авторы заявляют об отсутствии конфликта интересов.

Статья поступила в редакцию 19.04.2019; принята к публикации 20.05.2019; опубликована онлайн 27.06.2019

Relevance. The body physiological reserve (PR) is one of the most significant human biomedical parameters showing energy consumption of the body during physical strain (PS) and its recovery after the end of the exercises. It is advantageous to use the physiological reserve parameter of the body in a sports medicine for the assessment of the sportsman's functional reserve. This parameter characterises the capability of the sportsman to successfully solve assigned tasks. The functional reserves of the sportsman are characterised by his mental strength, skills and experience during solving of the assigned sport task. However, the sportsman's PR role is great, especially in energy consumption sports, as well as in the forecasting of the high sporting performance. Therefore, the problem of the formation of the biomedical parameters complex, which is significant for PR assessment and the system for assessing and forecasting of the sportsman capabilities, remain actual.

The aim of the investigation is to develop the method and the system of a sportsman's PR assessment allowing the investigation of a sportsman's PR during the training processes.

It is necessary to solve the following problems to accomplish a specific aim:

1. Formation of the biomedical parameters complex and the integral parameter characterising a sportsman's PR during the training process.

2. Development of the method of the biomedical investigation of a sportsman and assess a sportsman's PR, based on the complex of body system parameters, which represents body systems functioning.

3. Development of the generalized structure of the biotechnical system and the structure of the system of picking up, registration, processing and analysis of a sportsman's biomedical signals.

4. Development of a sportsman's wearable device for registration of the physiological parameters complex.

Methods of the problem solving and its results. Formation of the biomedical parameters complex and integral parameters which represent a sportsman's PR during the training process. Carbohydrates are combusting in muscle tissue during the physical activity and aerobic respiration, that leads to the production of carbon dioxide, water and heat emission. Continuous intake of carbohydrates and oxygen to the body cells is necessary for realization of this biochemical reaction. Cardiovascular system and respiratory system play an important role in providing of the physical activity. Heart rate (HR), pulse frequency (PF), and respiratory rate (RR) increase with the increase of physical strain. Circulating blood provides an income of carbohydrates and oxygen to body cells and getting a carbon dioxide and a water out. Thus, the body PR in the current moment will be determined, first of all, by the following parameters: HR, PF, RR. HR should be changed according to increase of PS. Efficiency of heart rate control could be characterized by the stress index by Baevsky (SIB) [1], [2]. The first signs characterizing metabolism change during PS are the increase of HR, the change of the heart rate variability (HRV). These signs reflect the mechanism of physiological function regulation in a sportsman's body and allow the characterization of general activity of the mechanisms which change the parameters of metabolism for the achievement of the optimal adaptive response and the adaptive reaction of a sportsman's body. The values of HRV depends upon the activity of the interaction between the sympathetic and parasympathetic parts of the nervous system. Therefore, HRV is characterized by the heart rate stability and maximum heart potential for the given value of PS. In addition, the change of the arterial tension (AT) value and HR reflects the income of carbohydrates and oxygen to the body cells required for doing the physical exercises. The value of heart rate reserve (HR_{res}) displays the capability of the body to do physical exercises on maximum strain level, characterizes the training level and a sportsman's recovery. The higher HR_{res} is the greater capability of standing high physical strain, and the wider the range of adaptive mechanisms of a sportsman's body [3]–[7].

It is important to provide a rhythmical oxygen delivery to the muscle tissue for the increase of the sportsman's performance capability and achievement of high results during the physical activity. It is no coincidence that blood doping is used in many sport disciplines that allows the chance to increase the number of erythrocytes. This leads to the increase of oxyhemoglobin level and oxygen delivery, and allows muscles to perform more stable and decrease its weakness. The key effect of the procedure is the increase of a sportsman's performance. Although the blood doping does not increase the maximum strength, it allows muscles to perform more intensely during a long time without weariness. Therefore, the arterial blood oxygen saturation, blood saturation (BS) is an important parameter for assessing of a sportsman's status. Increase of PS leads to the decrease of a sportsman's BS. It is necessary to provide a larger volume of oxygen to increase the training duration, but the respiratory systems could not pro-

vide it. According to this, application of oxyhemometry tools is important for control of BS and physical activity, because the estimation of a sportsman's BS dynamics is of a greater importance, not only during the training process, but also during the recovery period [4], [8]–[10].

The next group of parameters, which is changing under the PS influence and characterize the oxygen transport system, are RR and the duration of inspiration and expiration. The control of a sportsman's breath is one of the main tasks of the sport medicine and high-performance sport. Frequency decreases rapidly during the recovery. Therefore, determination of RR dynamics is of great importance for the assessment of a sportsman's reserves because of the high information capacity of this parameter [11]–[14]. Thus, the next valuable PR parameters are RR and BS level.

It is important to take into account the performance capability of the recovery during a sportsman's monitoring for complex assessment of his PR. The recovery rate is determined by the health status, the training level and the PR level of the surveyed sportsman. The following dependence could be observed: the higher body PR is the quicker recovery up to initial conditions of enhanced PR proceeds. Thus, the following physiological parameters characterizing PR of the body must be used for assessing of a sportsman's PR: HR, PF, HRV, SIB, SAT and DAT (the systolic and diastolic AT), RR, BS level. These parameters should be used for integral assessing of a sportsman's' body PR.

It is necessary to do a normalization of the particular parameters for integral assessing of the PR by the complex of the diagnostically significant parameters, because they have different dimensions. Each of the particular parameters must be estimated not by its absolute value, but by using a relative scale. The variation range of some of the parameters is the tenth of a unit, others are in the dozens and the hundreds. That requires that we represent these parameters at the same scale. Therefore, it is suggested to go from the absolute values of HR, PF, HRV, SIB, AT, RR, and BS levels to the relative values by using normalization of the terms of chosen values. For example, a particular sportsman's maximum performance or a particular age-group limit. For example, HR is set to be 190, SAT is set to be 200 mm Hg, RR – 40 breaths per minute, etc. Relative values of particular parameters after normalization will be in the range from 0 to 1.0.

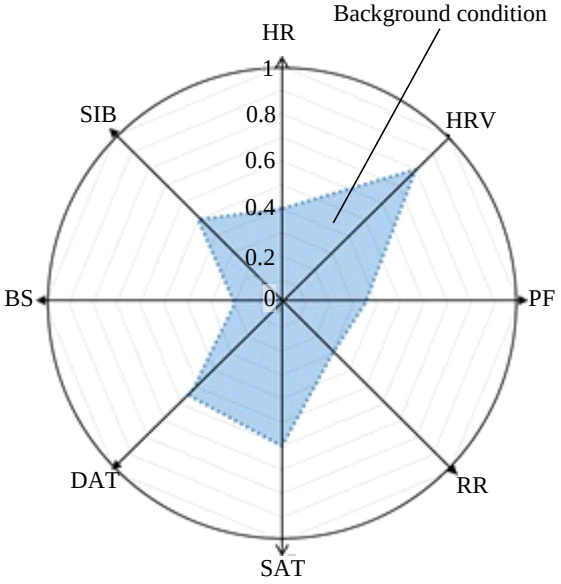

Fig. 1. Graphic representation of the integral PR parameter

$P_i(t)$ is the current absolute value of the particular parameter characterizing sportsman's PR, $i=\overline{1,N}$; where N is the number of parameters used for assessing a sportsman's PR, then the relative current particular value of parameter is derived by the expression $p_i(t)=\frac{P_i(t)}{P_{\lim}}$, where $P_{\lim}$ is the limit value of the particular parameter. Integral PR parameter $IP_{\mathrm{PR}}(t)$ could be determined either as the convolution of the particular parameters $IP_{\mathrm{PR}}(t)=$ $=p_1(t)\,p_2(t)\ldots p_N(t)=\prod p_i(t)$ or the vector in N-dimensional feature space or the N-sector circle diagram. In the latter case, integral parameter is characterized by the area of the N-sector diagram (Fig. 1).

The integral PR parameter $IP_{\mathrm{PR}}(t)$ is the current value of PR, which is determined by the current values of the particular parameters. Assessing the PR values before training, during training in the moments of the dozed strain change, and after training allows to investigate the reaction of a sportsman's body response to various levels of the dozed strain, and adaptive mechanics of the body for acting in extreme conditions. The following sportsman's PR parameters are of the interest for the coach and the sport medicine doctor (SM) – before training (background value), during training, after training, and recovery of a sportsman's PR after intensive training. In this relation, it is advantageous to estimate the values of the body PR at a particular point in time, the PR dynamics in time intervals during change of the dozed PS, and also PR dynamics

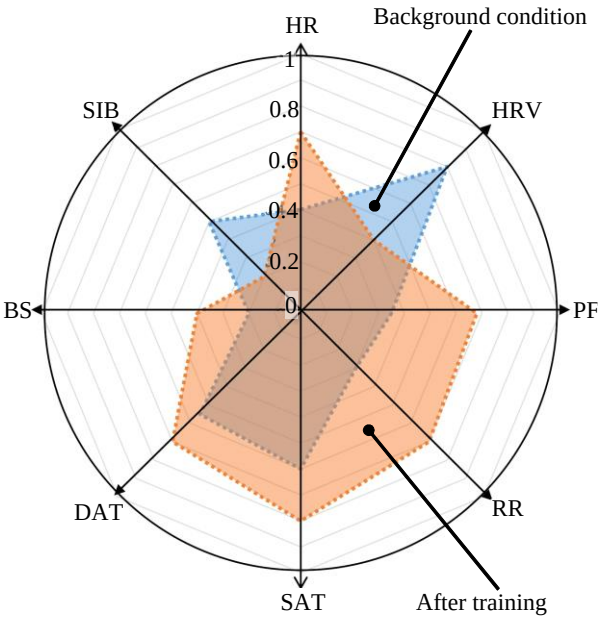

Fig. 2. Dynamic Parameter of Sportsman's Body PR

during the recovery of a sportsman's body after training (Fig. 2) [7], [11].

Development of the method of a sportsman's biomedical investigation and assessing of a sportsman's PR based on the complex of the body system parameters, which reflect the body system functioning. During the training procedure, the sportsman accomplishes various tasks with PS according to a schedule aimed on the formation of skills and experiences under a coach's leadership. This process usually includes several stages with brief pauses for task change and PS increase in between. It is important for the doctor and the coach to know how the sportsman's body PR will change during physical strain increase [15]–[17]. The quantity of the training procedure stages depends on a variety of factors: the training schedule, the sport discipline, a sportsman's health, etc. Let us use the following simplified scheme (Fig. 3) for explanation of the methodology of the development of the investigation method aimed on studying of a sportsman's body PR.

In accordance with the proposed scheme of the point in time $T_0, T_1, T_2, \ldots, T_k$ are used for assessing the sportsman's body potential capabilities.

The point in time T_0 – assessing of the initial (background) value of a sportsman's body PR before training. The training procedure starts right after the assessment of PR(T_0).

The point in time T_1 – the assessing of the PR(T_1) after the end of the first stage of training.

The point in time T_2 – assessment of the PR(T_2) after the end of the second stage of training.

The point in time T_k – assessment of the PR(T_k) after the end of the training process (*k*-th stage). Then $\mathrm{PR}(j\Delta t)$ are assessed on time intervals Δt for studying of the PR recovery time of the sportsman's body.

It is necessary to carry on following the procedure at each stage of the investigation of a sportsman's body PR [18]:

1. Picking up and the synchronous registration of a sportsman's biomedical signals, processing and analysis of these signals and the estimation of diagnostically significant parameters characterizing body PR: HR, PF, HRV, AT, RR, BS, SIB.

2. Assessment of the particular absolute and relative PR parameters, and the integral PR parameter of a sportsman's body. Assessment of the integral PR parameters at different stages of the training processes, assessing of the characteristics of the PR parameter dynamics and the sportsman's PR recovery parameters.

3. Revealing of the laws of changing of the integral PR parameter and the PR recovery parameter depending on the physical strain level used during the training process. Development of the e models of a sportsman's body PR changing, which represent the change of body potential capabilities in time.

4. Formation of the schedule and the training process correction with respect to a sportsman's body PR dynamics.

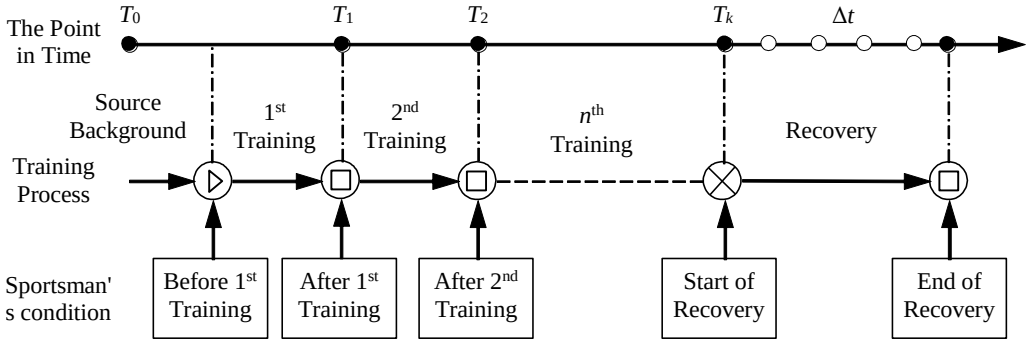

Fig. 3. The Scheme of Sportsman PR Investigation Procedure

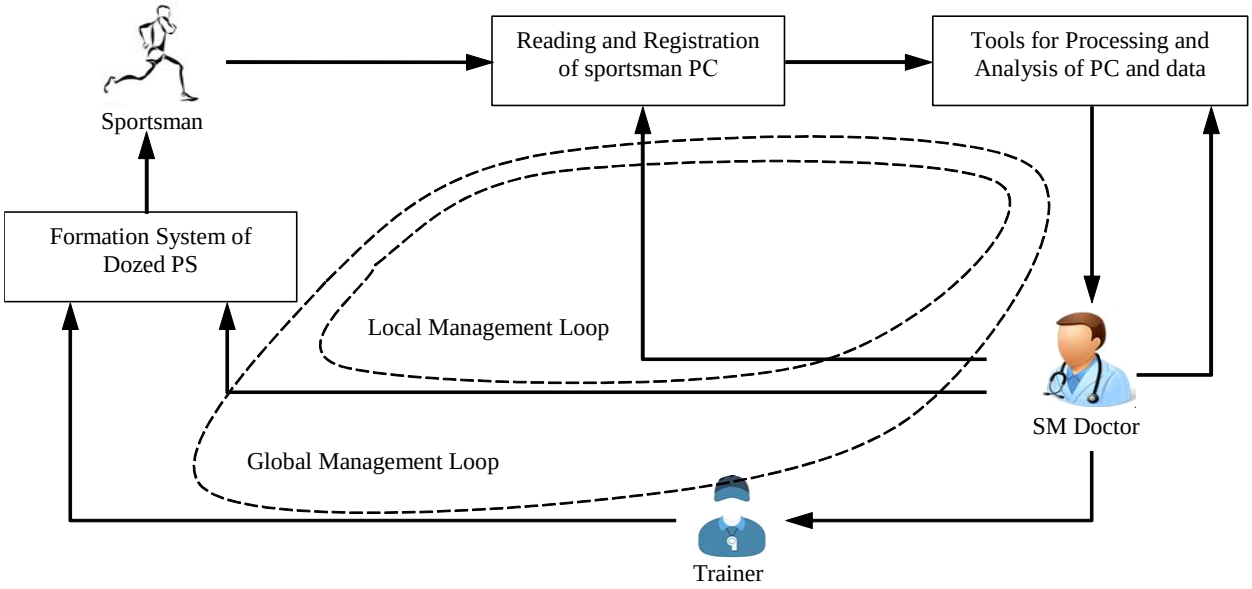

Fig. 4. Structure of Biotechnical System of Sportsman PR Assessing

Development of the generalized structure of the biotechnical system and the structure of the system of picking up, registration, processing, and analysis of a sportsman's biomedical signals. For a sportsman's PR research and assessment of his body's potential capabilities, the biotechnical system should include the elements providing the picking up and registration of a sportsman's biomedical signals, processing of the signals and assessment of the diagnostically significant parameters, assessment of the particular and integral PR parameters, assessment of the dynamical characteristics of the integral PR parameters and setting the dozed values of physical strain. Thus, the biotechnical system must have the following general structures (Fig. 4). It includes the described below functions that allow to be used the proposed system in the tasks of the distant monitoring of a sportsman's health status:

– Prolonged continuous synchronous registration of the physiological signal complex (ECG, signals of respiratory movement (SRM), photoplethysmogram (PPG), photo-oxyhemogram, etc.) characterizing a current sportsman's PR condition;

– Assessment and storage of the diagnostic parameters in the SM doctor's processing and analyzing device;

– Informational and medical care of the sportsman by SM doctor in the case of a critical condition appearance;

– Rapid review of the training efficiency and the schedule correction carried on by the coach in accordance with the global control loop.

The system assessing a sportsman's PR must provide the function of continuous control of a sportsman's health status during the training process to eliminate life-threatening conditions of the sportsman. Therefore, the system must have two control levels, which includes both the SM doctor and the coach:

1. The first control level assumes the local assessment of PR parameters by using the system of picking up and registration of a sportsman's physiological condition (PC) based on a sportsman's wearable device (SWD), the tools for processing and the analysis of PC and data based on a doctor's laptop computer (DLC). Using this loop, the SM doctor controls the operating regime: picking up and registration of PC, processing the method choice, analysis and displaying of a sportsman's PR, choosing and the correction of the research process program using the dozed PS.

2. The second loop provides a communication between SM doctor and coach to form sportsman's training activity (training schedule) with respect to the earlier obtained data of sportsman's PR. All sportsman's PR data downloaded to DLC is copied to the server for filling into the stored sportsman's electronic card. Having access to the server, coach can analyze the data of sportsman's PR dynamics during the current training or for a long period of sportsman's training, develop activities and make corrections of the sportsman's training schedule. In the case of emergency threatening to sportsman's life connection between SM doctor and coach must be direct (Fig. 4)

Development of a sportsman's wearable device for registration of the physiological signal complex. It is proposed to use SWD, which is the intellectual system for picking up and registration of a sportsman's PR, for a PR assessment during the training process [19]. Functional purpose of SWD is

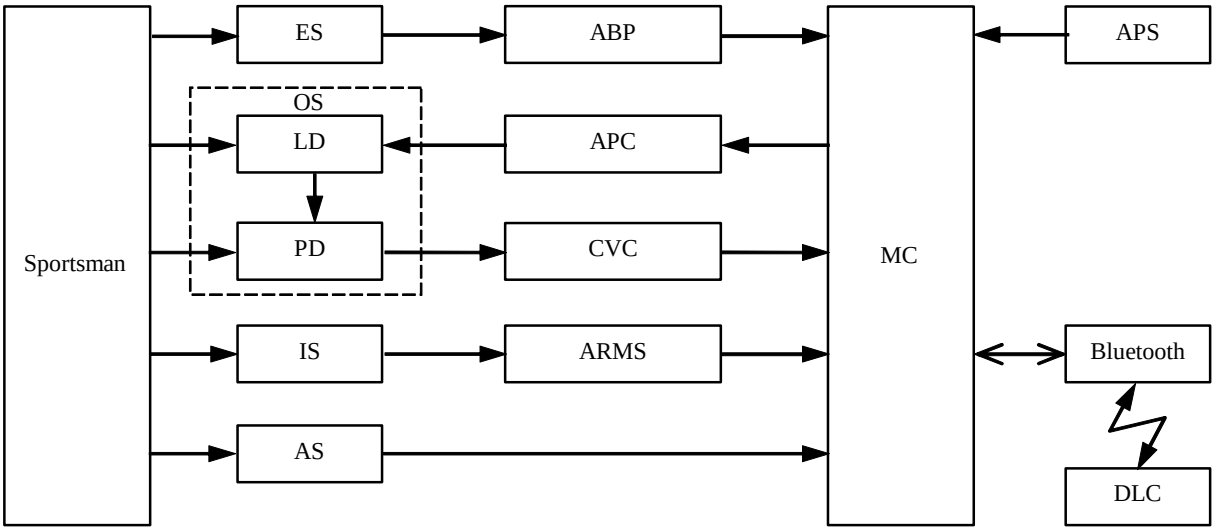

Fig. 5. Structure of System of Reading, Registration, Processing, and Analysis of Sports-Man's Data

providing of a continuous and synchronous registration of the sportsman's PC complex.

SWD (Fig. 5) provides the picking up and registration of SRM, ECG, PPG, muscle activity, characterizing activity of respiratory system and the cardiovascular system, movement apparatus during the training process. SWR should have minimal dimensions and weight, provide usability in the case of the prolonged monitoring, intellectual regimes of picking up, registration, processing, and analysis of biomedical data.

Picking up and registration of ECG is carried out using of the electrode system (ES) and the amplifier of a biopotentials (ABP).

The channel of registration of the wave signals and oxyhemometry includes the optical sensor (OS) based on a light diode (LD) and photodiode (PD), the amplifier of pulsed current (APC), and the current-to-voltage converter (CVC).

The channel of breath registration includes the inductive respiration sensor (IS) and the amplifier of the respiratory movement signal (ARMS).

The channel of muscle activity signal registration includes the digital accelerometer sensor (AS).

All registered signals applied to the input of the microcontroller (MC), analogue signals converts into a digital code using the microcontroller built-in analogue-to-digital converter. Then these signals are formed into the files of synchronous recording, which is transmitted to DLC using Bluetooth. It is reasonable to use the low-power microcontrollers for increase of the autonomous functioning of the laptop. Continuous prolonged functioning of the SWD is provided by the autonomous power source (APS).

Thus, the system of assessing of a sportsman's body PR have the spatial distributed structure. Such architecture allows one to distribute tasks, which are being solved by the monitoring system, to various levels, provide high efficiency of picking up, registration, processing and analysis of the biomedical signals and the assessment of the current value of sportsman's PR level during the training process.

Conclusion. 1. It is necessary to assess a sportsman's PR using the physiological signal complexes registered during the training process for the assessment of the sportsman's potential capabilities and forecasting of his results. Assessment of the complex of diagnostically significant parameters reflects the efficiency of a sportsman's respiratory system, cardiovascular system, and locomotor apparatus. A sportsman's condition should be characterized by the PR parameter at the current moment in time, and the dynamics of the parameter during the training process. Assessment of the PR dynamics after the end of the training process allows to assess PR recovery.

2. Proposed method of a sportsman's PR investigation and biotechnical structure with spatially distributed architecture allows a coach and an SM doctor to assess the efficiency of the sportsman's training process with respect to his potential capabilities and efficiently control training processes.

REFERENCES

1. Shlyk N. I., Baevskiy R. M. Heart Rate Variability. Theoretical Aspects and Practical Application. Abstracts and Reports IV All-Russian Symposium. Izhevsk, UdSU, 2008, 344 p. (In Russ.)

2. Baevskiy R. M., Ivanov G. G. Analysis of Heart Rate Variability Using Different Electrocardiographic Systems (Guidelines). *Vestnik aritmologii* [Bulletin arrhythmology], 2001, no. 24, pp. 65–86. (In Russ.)

3. Cheng T. M., Savkin A. V., Celler B. G., Su S. W., Wang L. Nonlinear Modeling and Control of Human Heart Rate Response during Exercise with Various Work Load Intensities. IEEE Transactions on Biomedical Engineering, 2008, vol. 55, iss. 11, pp. 2499–2508. doi: 10.1109/TBME.2008.2001131

4. Weng, K., Turk B., Dolores L., Nguyen T. N., Celler B., Su S., Nguyen H. T. Fast tracking of a given heart rate profile in treadmill exercise. 2010 Annual Intern. Conf. of the IEEE Engineering in Medicine and Biology. Buenos Aires, Argentina. 31 Aug.-4 Sept. 2010. Piscataway, IEEE, 2010, pp. 2569–2572. doi: 10.1109/IEMBS.2010.5626650

5. Stork M., Novak J., Zeman, V. Models of Some Physiological Parameters Based on Spiroergometric Exercise Test. 2011 Intern. Conf. on Applied Electronics. Pilsen, Czech Republic. 7-8 Sept. 2011. Piscataway, IEEE, 2011, pp. 1–6.

6. Paradiso M., Pietrosanti S., Scalzi S., Tomei P., Verrelli C. M. Experimental Heart Rate Regulation in Cycle-Ergometer Exercises. IEEE Transactions on Biomedical Engineering, 2012, vol. 60, iss. 1, pp. 135–139. doi: 10.1109/TBME.2012.2225061

7. Logier R., Dassonneville A., Chaud P., De Jonckheere J. A Multi Sensing Method for Robust Measurement of Physiological Parameters in Wearable Devices. 2014 36th Annual Intern. Conf. of the IEEE Engineering in Medicine and Biology Society. Chicago, IL, USA. 26-30 Aug. 2014. Piscataway, IEEE, 2014, pp. 994–997. doi: 10.1109/EMBC.2014.6943760

8. Plews D. J., Laursen P. B., Meur Y. L., Hausswirth C., Kilding A. E., Buchheit M. Monitoring Training with Heart-Rate Variability: How Much Compliance is Needed for Valid Assessment? International Journal of Sports Physiology and Performance, vol. 9, iss. 5, pp.783–790. doi: 10.1123/ijspp.2013-0455

9. Kaikkonen P. Post-exercise Heart Rate Variability: A New Approach to Evaluation of Exercise-Induced Physiological Training Load. Studies in Sport, Physical Education and Health. 2015, vol. 224, 88 p.

10. Zakynthinaki M. S. Modelling Heart Rate Kinetics. PloS one. 10(4), e0118263, pp. 1–26. doi: 10.1371/journal.pone.0118263

11. Ahmadi A. K., Moradi P., Malihi M., Karimi S., Shamsollahi M. B. Heart Rate Monitoring during Physical Exercise Using Wrist-Type Photoplethysmographic (PPG) Signals. 2015 37th Annual Intern. Conf. of the IEEE Engineering in Medicine and Biology Society (EMBC). Milan, Italy. 25-29 Aug. 2015. Piscataway,IEEE, 2015, p. 6166–6169. doi: 10.1109/EMBC.2015.7319800

12. Dong J. G. The Role of Heart Rate Variability in Sports Physiology. Experimental And Thera-Peutic Medicine. 2016, vol. 11, iss. 5, pp. 1531–1536. doi: 10.3892/etm.2016.3104

13. Bellenger C. R., Fuller J. T., Thomson R. L., Davison K., Robertson E. Y., Buckley J. D. Monitoring Athletic Training Status Through Autonomic Heart Rate Regulation: a Systematic Re-View and Meta-Analysis. Sports Medicine. 2016, vol. 46, iss. 10, pp. 1461–1486. doi: 10.1007/s40279-016-0484-2

14. Ornelas F., Nakamura F. Y., Dos-Santos J. W., Batista D. R., Meneghel V., Nogueira W. J., Brigatto F. A., Germano M. D., Sindorf M. A., Moreno M. A., Lopes C. R., 2017. Daily Monitoring of the Internal Training Load by the Heart Rate Variability: A Case Study. Journal of Exercise Physiology Online. 2017, vol. 20, iss. 1, pp. 151–163.

15. Stork M., Novak J., Zeman V. Dynamic Models of Some Physiological Parameters in Response to Exercise. 2017 Intern. Conf. on Applied Electronics (AE). Pilsen, Czech Republic. 5-6 Sept. 2017. Piscataway, IEEE, 2017, pp. 1–4. doi: 10.23919/AE.2017.8053622

16. Huang Y. C., Huang T. S. A Study of Physiological Responses to Different Forms of Exercise. 2017 IEEE 8th International Conference on Awareness Science and Technology (iCAST). 8-10 Nov. 2017. Taichung, Taiwan. Piscataway, IEEE, pp. 68–74. doi: 10.1109/ICAwST.2017.8256525

17. Stork M., Novak J., Zeman V. Modeling of Heart Rate During Exercise. 2017 11th Intern. Conf. on Measurement. Smolenice, Slovakia. 29-31 May 2017. Piscataway, IEEE, pp. 251–254. doi: 10.23919/MEASUREMENT.2017.7983583

18. Scott M., Graham K. S., Davis G. M. Cardiac Autonomic Responses during Exercise and Post-Exercise Recovery Using Heart Rate Variability and Systolic Time Intervals—a Review. Frontiers in Physiology. 2017, vol. 8, art. 301. doi: 10.3389/fphys.2017.00301

19. Nguyen Trong Tuyen, Tran Trong Huu, Nguyen Mau Thach, Yuldashev Z. M. System and Algorithm of Intelligent Biomedical Signal Processing and Analysis for Human Health Status Remote Monitoring System. Journal of the Russian Universities. Radioelectronics. 2018, no. 5, pp. 71–80. doi: 10.32603/1993-8985-2018-21-5-71-80 (In Russ.).

Nguyen Mau Thach – Postgraduate Student of Saint Petersburg Electrotechnical University "LETI". Teacher in Le Quy Don Technical University. The author of 14 scientific publications. Area of expertise: medical instrumentation; biomedical engineering; processing and analysis of biomedical signals.
E-mail: thachnguyen@mail.ru

Nguyen Trong Tuyen – Ph.D. in Engineering (2018), Teacher in Le Quy Don Technical University. The author of 29 scientific publications. Area of expertise: medical instrumentation; biomedical engineering; processing and analysis of biomedical signals.
E-mail: nguyentuyen1988@gmail.com

Tran Trong Huu – Ph.D. in Engineering (2018). Fellow Worker in Vietnam Military Medical University. The author of 27 scientific publications. Area of expertise: medical instrumentation; biomedical engineering; processing and analysis of biomedical signals.
E-mail: trantronghuu2007@gmail.com