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Ina I. Revinskaya*, Pavel V. Kamlach, Yauhen I. Liashchevich

*Belarusian State University of Informatics and Radioelectronics,
6, P. Brovka Str., 220013, Minsk, Republic of Belarus*

HARDWARE-SOFTWARE COMPLEX FOR STUDYING OF BREATHING VOLUME PARAMETERS

Abstract. In this paper, a developed hardware-software complex for studying volume parameters of breathing is considered. To estimate the volumetric parameters of breathing, a method for registering the movement of the chest and abdominal walls by changing the overall dimensions of the chest and abdomen with ranking according to the anatomical features of a person is proposed. A technique for researching the volumetric parameters of breathing based on the method of video recording of the movements of the chest and abdominal wall of a person was developed. The proposed method was used to estimate volume parameters of breathing among men aged 20–22 years. BMI (body mass index) ranged from 18.2 to 30.1 kg/m². The research of volumetric parameters of respiration was carried out using the hardware-software complex and the proposed technique for registering the biomechanics of breathing. Conclusions about the relation between volumetric parameters of breathing and the values of changes in the overall dimensions of the chest and abdomen during respiration were drawn. A correlation-regression analysis of the volumes of inhaled/exhaled air and the values of deviations of the overall dimensions of the chest and abdomen was carried out. The results obtained indicate a strong relation between volumetric parameters of breathing and the values of deviations in the overall dimensions of the chest and abdomen.

Keywords: biomechanics, breathing, COVID-19, spirometry, videocamera, lung volumes

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Information about the authors: *Ina I. Revinskaya** – Graduate Student of the Department of Electronic Technology and Engineering, Belarusian State University of Informatics and Radioelectronics. https://orcid.org/0000-0003-2664-7075. E-mail: inna_revinskaya@bsuir.by; *Pavel V. Kamlach* – Cand. Sci. (Engineering), Associate Professor, Associate Professor of the Department of Electronic Engineering and Technology, Belarusian State University of Informatics and Radioelectronics. https://orcid.org/0000-0002-2329-9063. E-mail: kamlachpv@bsuir.by; *Yauhen I. Liashchevich* – Graduate Student of the Department of Electronic Technology and Engineering, Belarusian State University of Informatics and Radioelectronics. https://orcid.org/0000-0002-8218-6544. E-mail: e.leshchevich@bsuir.by

Contribution of the authors: *Ina I. Revinskaya* – development of the hardware-software complex, planning and conducting research, statistical processing of the obtained results, writing and formatting of the text of the manuscript; *Pavel V. Kamlach* – formulation of the task for the research, discussion of the results, editing of the text of the manuscript; *Yauhen I. Liashchevich* – development of the hardware-software complex, conducting research and editing of the text of the manuscript.

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Оригинальная статья

И. И. Ревинская*, П. В. Камлач, Е. И. Лещевич

Белорусский государственный университет информатики и радиоэлектроники, ул. П. Бровки, 6, 220013, Минск, Республика Беларусь

АППАРАТНО-ПРОГРАММНЫЙ КОМПЛЕКС ДЛЯ ИССЛЕДОВАНИЯ ОБЪЕМНЫХ ПАРАМЕТРОВ ДЫХАНИЯ

Аннотация. Приводится описание разработанного аппаратно-программного комплекса для исследования объемных параметров дыхания. Для определения указанных параметров дыхания (жизненной емкости легких и дыхательного объема) предлагается способ регистрации движения грудной и брюшной стенок по изменению габаритных размеров грудной клетки и живота с ранжированием по анатомическим особенностям человека. Разработана методика исследования объемных параметров дыхания, основанная на методе видеосъемки движения грудной клетки и брюшной стенки человека. Предложенная методика была использована при оценке объемных параметров дыхания среди мужчин в возрасте 20–22 лет. Индекс массы тела (ИМТ) варьировался от 18,2 до 30,1 кг/м^2. С помощью аппаратно-программного комплекса проведены исследования объемных параметров дыхания совместно с предложенным способом регистрации биомеханики дыхания, сделаны выводы о взаимосвязи объемных параметров дыхания и значений отклонений габаритных размеров грудной клетки и живота во время дыхания. Проведен корреляционно-регрессионный анализ объемов вдыхаемого/выдыхаемого воздуха и значений отклонений габаритных размеров грудной клетки и живота. Полученные результаты свидетельствуют о сильной взаимосвязи объемных параметров дыхания и значений отклонений габаритных размеров грудной клетки и живота.

Ключевые слова: биомеханика, дыхание, COVID-19, спирометрия, видеорегистратор, объем легких

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Информация об авторах: *Ревинская Инна Ивановна** – аспирант кафедры электронной техники и технологий, Белорусский государственный университет информатики и радиоэлектроники. https://orcid.org/0000-0003-2664-7075. E-mail: inna_revinskaya@bsuir.by; *Камлач Павел Викторович* – кандидат технических наук, доцент, доцент кафедры электронной техники и технологии, Белорусский государственный университет информатики и радиоэлектроники. https://orcid.org/0000-0002-2329-9063. E-mail: kamlachpv@bsuir.by; *Лещевич Евгений Игоревич* – аспирант кафедры электронной техники и технологий, Белорусский государственный университет информатики и радиоэлектроники. https://orcid.org/0000-0002-8218-6544. E-mail: e.leshchevich@bsuir.by

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Introduction. Breathing movements of the chest and abdomen are carried out by the respiratory muscles and closely correlate with the increase and decrease in the volume of the chest, which in turn describes changes in the volume of inhaled and exhaled air [1]. Since external respiration is carried out by changes in chest volume and concomitant changes in lung volume, it is worth mentioning how the biomechanics of breathing occurs.

Inhalation occurs due to an increase in the volume of the chest cavity in three directions – vertical, sagittal and frontal [2, 3]. This is due to the rise of the ribs and the lowering of the diaphragm. The volume of the chest and the lungs in it increase on inspiration; at the same time, the pressure in them decreases, and air enters the pulmonary alveoli through the airways. During inhalation, the respiratory muscles of a person overcome a number of forces: 1) the severity of the ribs raised upward; 2) elastic resistance of costal cartilages; 3) the resistance of the walls of the abdomen and abdominal viscera, pressed downwards by the descending dome of the diaphragm.

Exhalation is carried out passively: the respiratory muscles relax, under the influence of these forces, the ribs fall, and the diaphragm rises. As a result, the volume of the chest decreases. The abdominal muscles contract and push the abdominal organs and the dome of the diaphragm upward. On exhalation, the volume of the chest, and, consequently, of the lungs, decreases, the pressure in the alveoli increases and the air comes out of the lungs.

Classical research methods for respiratory function (spirometry, pneumotachometry, etc.) make it possible to identify possible pathologies of respiratory function, respiratory diseases such as COPD, asthma, bronchitis, etc. Spirometry is designed to measure the volume of inhaled and exhaled air and is considered the "gold standard" for diagnosing chronic obstructive pulmonary disease [4].

Preparation for spirometry requires the use of disposable consumables (mouthpiece, antibacterial filter, replaceable mesh, etc.) [4], regular sanitization of the measuring tube from sputum after each patient, which is especially important in the context of the COVID-19 pandemic. In addition, after regular sanitization (in the case of disassembly and assembly of the measuring tube), calibration of the device is required, which increases the time it takes to prepare the equipment for use. During measurements, the use of a nose clip is mandatory for reliable results, which causes discomfort to the subject and may affect the normal breathing pattern of the subject. The psychological factor of influence on the results of the research should be taken into account. In addition, spirometry does not allow for long-term studies of breathing parameters [4, 5].

Currently, it is becoming more and more important to use both contact and non-contact methods for researching the function of external respiration. Recent scientific research in this area substantiates the possibility of using methods based on the analysis of the movement of the chest and abdomen [6]. There are three approaches to breath analysis: based on the recording of chest deformation caused by respiratory activity (strain sensors); based on changes in transthoracic impedance (impedance sensors); based on the recording of chest movements (for example, chest tilt, acceleration and speed) using an accelerometer, gyroscope, magnetometer.

These methods make it possible to indirectly estimate the volumetric parameters of breathing from the values obtained from the sensors (change in the impedance of the chest during breathing, change in the capacitance of the sensor, resistance, etc.) due to the movement of the chest and abdominal cavity. Thus, it is relevant and promising to develop methods for researching the function of external respiration by the movement of the chest and abdomen. Such methods will solve the previously described disadvantages.

In this paper, it is proposed to use the method of recording the movement of the chest and abdominal walls by changing the overall dimensions of the chest and abdomen with ranking according to the anatomical features of a person to determine the volumetric breathing parameters.

Material and methods. For studying the volumetric parameters of breathing a hardware-software complex (HSC) was developed. The structure of the HSC (Figure 1) includes a spirometer, a video camera and a personal computer (PC).

An automated multifunctional spirometer MAC-1 was used to measure of volume capacity (*VC*) and tidal volume (V_t) The main technical characteristics of the spirometer: air volume measurement limit 1–8 dm^3, measured flow up to – 18 l/s, accuracy class – 5 %, automatic quality control tests in accordance with ATS-1994 and ATS/ERS-2005 [7]. Spirometry was used as a reference method for measuring the volume of inhaled and exhaled air and to estimate the validity of the proposed method of measurement based on the analysis of the movement of the chest and abdomen.

A video camera was used to record the movements of the chest and abdominal walls of the subject during breathing. According to the obtained video fragments, the values of deviations of the chest and abdomen were calculated. Main technical characteristics of the video camera: screen resolution

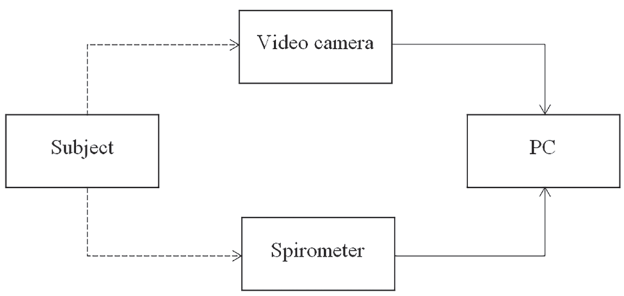

Figure 1. Structural diagram of the hardware-software complex for the study of the volumetric parameters of breathing

1080 × 1920, number of matrix dots – 12 MP, maximum frames per second – 240 frames/s (1280 × 720), optical stabilization. The video camera was mounted on a tripod at a distance of 50–60 cm to the right of the subject. The height of the video camera was adjusted depending on the height of the subject. On the left of the subject, a calibration board was placed with a division value of 0.5 and 1.0 cm along the *X* axis, and 2 cm along the *Y* axis.

Using a PC with specialized software, video files were divided into video fragments, video fragments were processed, data was extracted from the spirometer, and the statistical analysis of the obtained experimental data was carried out.

Method for assessing volumetric parameters of breathing. A technique for registering volumetric parameters of breathing using the hardware-software complex was developed and includes six steps:

1. Collection of anamnesis (age, height, weight, presence of diseases, including chronic ones).
2. Placement of markers on the human body (Figure 2, *a*–*d*) – in the sagittal plane, in the direction of the video camera. The first mark was attached at the midpoint relative to the line of the armpits and nipples, the second mark is at the level of the solar plexus, the third – at the level of the abdomen (waist). The marks help to determine correctly the places, at the level of which the deviations of the overall dimensions of the chest and abdomen were calculated.
3. The subject must be properly seated.
4. Installation of a video camera and a calibration board. The height of the video camera and the board can be adjusted depending on the height of the subject. The video camera must be placed parallel to the measurement plane.
5. Setting up the spirometer. Entering patient data.
6. Starting the video camera and performing spirometry tests.

Spirometry tests were carried out in accordance with the guidelines of the Ministry of Health of the Republic of Belarus [8]. During the research, the current lung volumes were assessed and, at the same time, the images obtained by the video camera were recorded during calm breathing on inspiration (see Figure 2, *a*), on exhalation (see Figure 2, *b*), then, on command, the subject took a deep breath (see Figure 2, *c*) and calm full exhalation (see Figure 2, *d*), respectively.

The determination of the correlation of volumetric breathing parameters (volume capacity) and the values of deviations of the overall dimensions of the chest and abdomen is computed by six levels as shown in Figure 2, *a-d*. Chest movements are determined by points A, B, C, abdominal movements – by points D, E, F. The value Δx_i was determined as a deviation from the minimum difference in the coordinates of the extreme points of the back and chest (or abdomen), index *i* denotes the number of measurements.

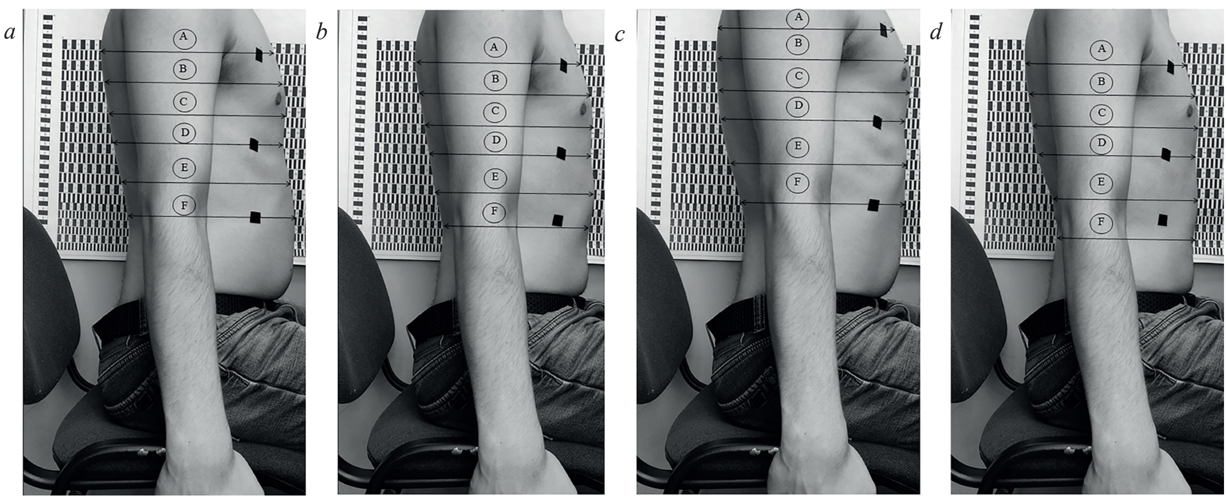

Figure 2. Fragments of video recording during the spirometry test: *a* – inspiration, *b* – expiration, *c* – deep breath, *d* – quiet full exhalation; estimation of deviations of the chest and abdomen is computed by six levels: A – at the level of the armpit; B – as the midpoint between A and C; C – 2 cm below the nipple; D – at the level of the solar plexus (diaphragm); E – the midpoint between D and F; F – at the level of the maximum deflection of the abdomen during breathing

To assess the nonlinear relationship between the volumes of inhaled and exhaled air and the deviation values, the correlation ratio [9, 10] is calculated by the formula

$$\eta = \sqrt{1 - \frac{\sigma_{\text{res}}^2}{\sigma^2}} = \sqrt{1 - \frac{\sum (y_i - \hat{y})^2}{\sum (y_i - \bar{y})^2}}, \quad (1)$$

where σ_{res} is the residual dispersion, σ is the variance of the actual values of the resulting feature, $\hat{y}$ are the theoretical values obtained from the regression equation $\bar{y}$ is the arithmetic mean deviation of value and y_i are the empirical values.

The root expression of the correlation relationship is the coefficient of determination and is calculated by the formula

$$R^2 = 1 - \frac{\sum (y_i - \hat{y})^2}{\sum (y_i - \bar{y})^2}. \quad (2)$$

The coefficient of determination shows how closely the observed values adjoin the regression line.

To check the adequacy of the regression model [10], Student's *t*-test is used and is calculated by the formula and was signed as t_η

$$t_\eta = \frac{\eta}{m_\eta} = \eta\sqrt{\frac{N-2}{1-\eta^2}}, \quad (3)$$

where $(N - 2)$ is the number of degrees of freedom at a given significance level and sample size N; m_η is the standard error of correlation ratio η. The standard error for the correlation coefficient can be written as $\eta \pm m_\eta$.

Result and discussion. Research on the biomechanics of breathing was carried out on the basis of the Department of Electronic Technique and Technology of the Belarusian State University of Informatics and Radioelectronics. According to the method described above using the hardware-software complex, 26 people (men) aged from 20 to 22 years were researched, while the subjects were divided into two groups according to the value of the body mass index (BMI): 18.2–25.0 kg/m² (normal) and 25.0–30.1 kg/m² (overweight).

For each subject, the correlation coefficients were calculated by six levels A–F (see Figure 2, *a*–*d*). When assessing the parameters from the group with normal BMI, a subgroup with the highest was identified (6 people, age 20–22 years, height 169–182 cm, weight 55–70 kg, BMI 19.3–21.5 kg/m²).

Figure 3, *a*–*f* shows the dependency of volume capacities on the values of deviations of the chest and abdominal walls for this subgroup for levels A–F. On the *x*-axis the deviations of the chest / abdomen Δx_1, Δx_2, Δx_3 in centimeters (cm) are shown, on the *y*-axis – volume capacity in liters (L).

The approximation curve describes a non-linear functional relationship between the experimental data in the form of a polynomial curve. The non-linear relationship is explained by the fact that in the process of breathing, the lung volumes changes together with the movements of the walls of the chest and abdomen in the horizontal, sagittal and frontal planes. The measurements were carried out in the sagittal plane, since during normal breathing the body walls move with the largest amplitude.

Table summarizes the calculated correlation coefficients η_i (taking into account the standard error of the correlation coefficients m_η) and determination coefficients R^2.

The values of the correlation relation and the coefficient of determination for points A–D

Parameter / Point	A (Δx_1)	B (Δx_2)	C (Δx_3)	D (Δx_4)	E (Δx_5)	F (Δx_6)
Correlation relation $\eta \pm m_\eta$	0.92 ± 0.08	0.92 ± 0.08	0.98 ± 0.05	0.84 ± 0.11	0.66 ± 0.16	0.47 ± 0.19
Determination coefficient R^2	0.84	0.84	0.95	0.70	0.44	0.22

The experimental data are closest to the approximating curve at level C (Figure 3, *c*), correlation relation η = 0.98 ± 0.05, for levels A and B η = 0.92± 0.08 (Figure 3, *a*, *b*). Dispersion value for point D is significant (Figure 3, *d*), but there is still a strong relation. The largest dispersion of values and the lowest values of the correlation ratio for points E (η = 0.66) and F (η = 0.47) can be explained by the fact that the subjects were dominated by the thoracic type of breathing, and the movement of the chest and abdomen occurs inconsistently.

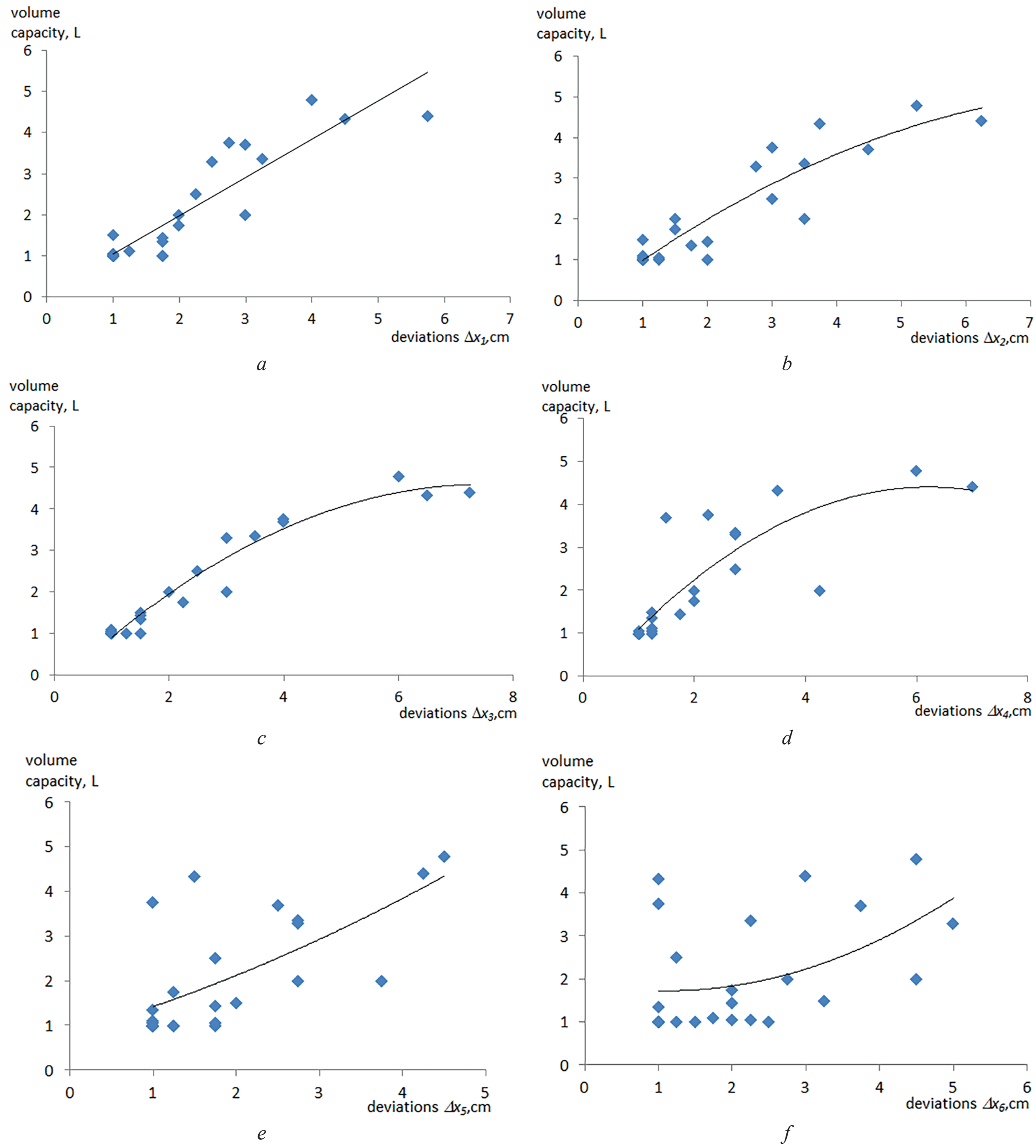

Figure 3. Scatterplots between volume capacity measurements and deviations of the chest and abdomen:
a – at level A, *b* – at level B, *c* – at level C, *d* – at level D, *e* – at level E, *f* – at level F

Conclusion. The hardware-software complex was developed to estimate the volumetric parameters of breathing. It includes a spirometer, a video camera and a personal computer with specialized software. The research of volumetric parameters of respiration was carried out using the hardware-software complex and the proposed technique for registering the biomechanics of breathing.

The obtained results confirm the possibility of using the developed hardware-software complex in the study of lung volumes. Applying the correlation-regression analysis of the experimental results, it was found that the polynomial regression model most accurately describes the tightness of the relationship between the volume capacity and the deviations in the overall dimensions of the chest. The proposed hardware-software complex will allow in the future to estimate the volume capacity in real-time under conditions of long-term monitoring, where the use of standard research methods is difficult.

References

1. Dubrovsky V. I., Fedorova V. N. *Biomechanics*. Moscow, VLADOS-PRESS, Publ., 2003. 550 p. (in Russian).

2. Revinskaya I. I., Kamlach P. V., Madveiko S. I., Kosareva A. A., Bondarik V. M. Application of linear filtering in the evaluation of respiratory parameters. *BIG DATA and Advanced Analytics = BIG DATA i analiz vysokogo urovnya: sbornik materialov V Mezhdunarodnoi nauchno-prakticheskoi konferentsii* [BIG DATA and Advanced Analytics = BIG DATA and High-Level Analysis: Collection of Materials of the 5th International Scientific and Practical Conference]. Minsk, 2019, pp. 27–32 (in Russian).

3. Davydchenko S. V., Bova A. A. *The Study of the Ventilation Function of the Lungs in Clinical Practice*. Minsk, Belarusian State Medical University, 2007. 112 p. (in Russian).

4. Chu M., Nguyen T., Pandey V., Zhou Y., Pham H. N., Bar-Yoseph R., Radom-Aizik S. [et al.]. Respiration rate and volume measurements using wearable strain sensors. *npj Digital Medicine,* 2019, vol. 2, iss. 1, art. ID 8. https://doi.org/10.1038/s41746-019-0083-3

5. Moeyersons J., Morales J., Seews N., Van Hoof C., Hermeling E., Groenendaal W., Willems R. [et al.]. Artefact Detection in Impedance Pneumography Signals: A Machine Learning Approach. *Sensors*, 2021, vol. 21, iss. 8, p. 2613. https://doi.org/10.3390/s21082613

6. Massaroni C., Nicolò A., Lo Presti D., Sacchetti M., Silvestri S., Schena E. Contact-Based Methods for Measuring Respiratory Rate. *Sensors*, 2019, vol. 19, iss. 4, p. 908. https://doi.org/10.3390/s19040908

7. Miller M. R., Hankinson J., Brusasco V., Burgos F., Casaburi R., Coates A., Crapo R. [et.al.]. Standardisation of spirometry. *European Respiratory Journal*, 2005, vol. 26, p. 319–338. https://doi.org/10.1183/09031936.05.00034805

8. Turina O. I., Lapteva I. M., Kalechits O. M., Manichev I. A., Shcherbitsky V. G. *Organization of Work on the Study of the Functional State of the Lungs Using Spirography and Pneumotachography and the Use of These Methods in Clinical Practice*. Minsk, 2002. 81 p. (in Russian).

9. Kharchenko M. A. *Correlation Analysis*. Voronezh, Publ. House of Voronezh State University, 2008. 31 p. (in Russian).

10. Gusarov V. M. *Statistics*. Moscow, UNITY-DANA Publ., 2003. 463 p. (in Russian).