An application supporting the educational process of the respiratory system obstructive diseases detection

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Abstract: The paper presents a description of functioning of a platform supporting the detection of obstructive diseases in the respiratory system education process. A 16-parameter model of the respiratory system simulated in the MATLAB/Simulink environment was set in the role of the tested patient. It has been linked to the control layer, developed in the LabVIEW environment, using the SIT library (Simulation Interface Toolkit). This layer is responsible for the modification of the model's parameters and the generation of the results of the respiratory impedance measurements using forced oscillation method. The application is a solution that provides a lot of flexibility in the education of students studying courses related to biomedical engineering and health sciences, and can easily be implemented to work as a problem-oriented e-learning solution.

Keywords: computer application, obstructive diseases, lungs

1. Introduction

The respiratory system is one of the most complex systems of the human body. The proper operation of gas exchange is necessary in order to maintain vital functions, and any disturbance in its operation can lead to a significant deterioration in the quality of life. Diagnosing various diseases and disorders in the functioning of the respiratory system is not an easy issue. The high effectiveness of the developed diagnostic methods resulted in a significant increase in detection of abnormalities [1–3], but often the analysis of the diagnostic tests results require from the professionals (doctors, technicians etc.) extensive knowledge and experience. A substantial simplification of the training process of highly qualified specialists is therefore applying e-learning and problem-oriented solutions PBL (Problem Based Learning).

The application developed by the authors allows to modify the parameters of the model in order to simulate respiratory obstructive diseases. Each parameter of the model is assigned to a specific anatomical structure, which allows an intuitive operation of the application. The virtual patient frequency method results are then displayed on the screen in order to visualize the effect of lesions on the respiratory mechanics. The presentation of the results in a graphic form acts as a feedback loop, which allows the person conducting the teaching to show the changes in the test results caused by physiological phenomena in the examined anatomical structures. The application allows for not using real diagnostic equipment excessively in teaching activities and enables one to analyze the results obtained for rare diseases, in the absence of the patients affected by that. In the future, such teaching platforms can become a basis for the construction of expert systems aiding e.g. diagnostic processes for medical specialists.

To test the application, two cases of clinical obstructive pulmonary disease (asthma) were modeled. The choice of this disease results from the fact that it is one of the most common diseases of the respiratory system, resulting in the large availability of scientific publications on it. In addition, pathological physiology caused by this disease, can be related directly to the specific parameters of the assumed model.

2. The universal model of the respiratory system

For developing the respiratory system model in the MATLAB/Simulink environment, a 16 element model (fig. 1) proposed in [4–5] was used. It is a combination of a 10 element model proposed in [6–7], and a 6 element model of the upper respiratory tract [8–9]. The advantage of the used model is a large flexibility in modeling many diseases due to the distinctiveness of almost any anatomical structure. The values of the physical parameters used in the model were collected on the basis of the literature [4, 6].

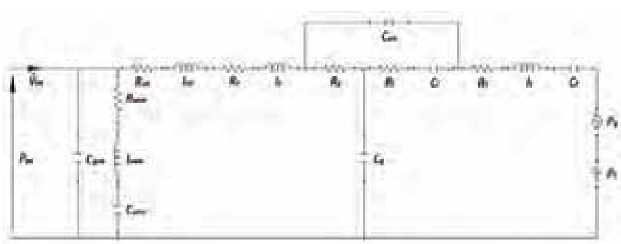

Fig. 1. The model of human respiratory system modeled in the application [15]:
R_{uaw} – resistance of the walls of the upper respiratory tract [$cmH_2O \cdot s \cdot l^{-1}$], R_{ua} – resistance of the upper respiratory tract [$cmH_2O \cdot s \cdot l^{-1}$], R_c – resistance of the central respiratory tract [$cmH_2O \cdot s \cdot l^{-1}$], R_p – resistance of the peripheral respiratory tract [$cmH_2O \cdot s \cdot l^{-1}$], R_l – lung tissue resistance [$cmH_2O \cdot s \cdot l^{-1}$], R_t – thoracic wall resistance [$cmH_2O \cdot s \cdot l^{-1}$], I_{uaw} – upper respiratory tract walls inertance [$cmH_2O^2 \cdot s \cdot l^{-1}$],

I_{ua} – upper respiratory tract inertance $[cmH_2O^2 \cdot s \cdot l^{-1}]$, I_c – central respiratory tract inertance $[cmH_2O^2 \cdot s \cdot l^{-1}]$, I_t – thoracic wall inertance $[cmH_2O^2 \cdot s \cdot l^{-1}]$, C_{gua} – oral cavity gas compliance $[cmH_2O^{-1} \cdot l]$, C_{uaw} – upper respiratory tract walls compliance $[cmH_2O^{-1} \cdot l]$, C_{aw} – bronchial walls compliance $[cmH_2O^{-1} \cdot l]$, C_g – alveoli gas compliance $[cmH_2O^{-1} \cdot l]$, C_l – lung tissue compliance $[cmH_2O^{-1} \cdot l]$, C_t – thoracic wall compliance $[cmH_2O^{-1} \cdot l]$, P_g – variable breathing cycle pressure $[cmH_2O]$, P_t – thorax tissue tension $[cmH_2O]$, P_{ao} – respiratory tract outlet pressure $[cmH_2O]$, dV_{ao}/dt – respiratory tract outlet flow [l/s]

Rys. 1. Model układu oddechowego człowieka zamodelowany w aplikacji [15]:
R_{uaw} – oporność ścian górnych dróg oddechowych $[cmH_2O \cdot s \cdot l^{-1}]$, R_{ua} – oporność górnych dróg oddechowych $[cmH_2O \cdot s \cdot l^{-1}]$, R_c – oporność centralnych dróg oddechowych $[cmH_2O \cdot s \cdot l^{-1}]$, R_p – oporność peryferyjnych dróg oddechowych $[cmH_2O \cdot s \cdot l^{-1}]$, R_l – oporność tkanek płuc $[cmH_2O \cdot s \cdot l^{-1}]$, R_t – oporność ścian klatki piersiowej $[cmH_2O \cdot s \cdot l^{-1}]$, I_{uaw} – inertancja ścian górnych dróg oddechowych $[cmH_2O^2 \cdot s \cdot l^{-1}]$, I_{ua} – inertancja górnych dróg oddechowych $[cmH_2O^2 \cdot s \cdot l^{-1}]$, I_c – inertancja centralnych dróg oddechowych $[cmH_2O^2 \cdot s \cdot l^{-1}]$, I_t – inertancja ścian klatki piersiowej $[cmH_2O^2 \cdot s \cdot l^{-1}]$, C_{gua} – podatność gazu w jamie ustnej $[cmH_2O^{-1} \cdot l]$, C_{uaw} – podatność ścian górnych dróg oddechowych $[cmH_2O^{-1} \cdot l]$, C_{aw} – podatność ścian oskrzeli $[cmH_2O^{-1} \cdot l]$, C_g – podatność gazu pęcherzyków płucnych $[cmH_2O^{-1} \cdot l]$, C_l – podatność tkanek płuc $[cmH_2O^{-1} \cdot l]$, C_t – podatność ścian klatki piersiowej $[cmH_2O^{-1} \cdot l]$, P_g – zmienne ciśnienie cyklu oddechowego $[cmH_2O]$, P_t – naprężenie tkanek klatki piersiowej $[cmH_2O]$, P_{ao} – ciśnienie u wylotu dróg oddechowych $[cmH_2O]$, dV_{ao}/dt – przepływ u wylotu dróg oddechowych [l/s]

The last step of the modeling is to analyze physiological changes caused by asthma. To achieve this, a modification of the model parameters shown in fig. 1 was proposed. The modified parameters will be used to test the, proposed for educational purposes, application. Asthma is a disease that causes airway obstruction over their entire length. Bronchial obstruction, causes a change of their resistance and inertance. According to [10–11], the change in resistance is proportional to the fourth power of the bronchi radius (assuming laminar flow), whereas inertance – the square of the radius. Based on a review of the literature [10, 12–13], changes in the parameters of the model in fig. 1 were made, which are shown in tab. 1.

Tab. 1. The values of physical parameters representing the patient's considered health statuses

Tab. 1. Wartości wielkości fizycznych reprezentujących rozpatrywane stany zdrowia pacjenta

The examined patient's state	Central airways		Distal airways
Healthy	*Rc*	*Ic*	*Rp*
Asthma case 1	5 *Rc*	2 *Ic*	5 *Rp*
Asthma case 2	2.5 *Rc*	1.5 *Ic*	2.5 *Rp*

3. Control layer

The Control Layer of educational application was created with LabVIEW environment of National Instruments Corporation and its user panel is illustrated in fig. 3. It consists of a control panel, on which all the changes in the physical parameters R_c, I_c oraz R_p are made. These changes result in modifications to the mechanics of the respiratory system, which are presented in charts. Mechanics examination is made with the use of the forced oscillation method (Forced Oscillation Technique, FOT). This method has been described in many publications, e.g. [14–17] and has gained wide acceptance and recognition because of the high sensitivity and the effectiveness of detection of early flow limitation phenomenon [15, 17]. FOT algorithm is illustrated in fig. 2. The essence of FOT is to provide the pressure wave P(t), containing one or several frequencies, at the patient's mouth. Amplitude of the pressure wave A can be changed with the knob located on the control panel. As a result of these actions, the primary breathing waveforms of pressure P_{ao}(t) and flow dV_{ao}(t)$/dt$ are modified to a form including higher harmonics. The measurement data of the resulting pressure wave P_{aof}(t) and flow dV_{aof}(t)$/dt$ is then subjected to sampling and Fourier transformation. Course of lung impedance in frequency domain is obtained by dividing the result pressure and frequency data (fig. 2).

The result of the application calculations are the waveforms of the real and imaginary impedance Z(f). Those waveforms, obtained with frequency methods, can be then used for purposes of educational analyses. As a complement to the results of lung mechanics, both pressure and flow time courses with the oral cavity reference (fig. 1) are displayed.

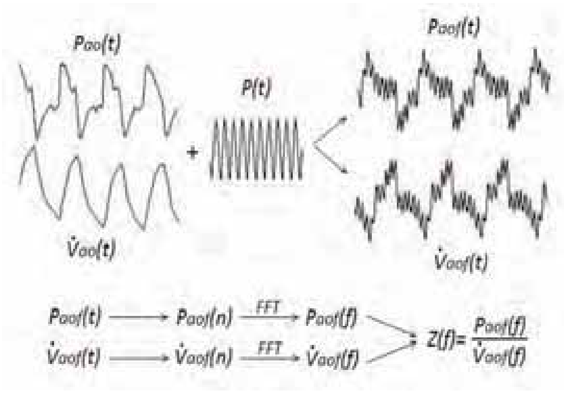

Fig. 2. Algorithm of FOT method based on [18]

Rys. 2. Algorytm metody FOT [18]

Control layer was connected with the MATLAB/Simulink respiratory system model through Simulation Interface Toolkit. It is contained into the set of libraries of the LabVIEW environment and its task is to establish a virtual data server, used by the connected applications. Moreover, the user has the ability to save the results of frequency analysis in the form of a text file and, if he has a need, upload up to two frequency courses stored previously. That data will be plotted along with the currently analyzed results.

4. The results of diagnostic tests for the considered diseases

The model presented in fig. 1 has been subjected to portray the application's diagnostic process and its results. In order to map the healthy human respiratory system mechanics (tab. 1), necessary changes of model's parameter values have been made with instruments placed on the control panel. The simulation results with the visualization of the time course of pressure, or flow rate with the oral cavity reference in real time. Then, after a few seconds of the measurement, the application starts the calculation process of pulmonary mechanics according to fig. 2. Figure 3 illustrates the results of calculations of the healthy patient respiratory system mechanics, complemented with airflow time course with the oral cavity reference. In order to model respiratory mechanics changes, caused by asthma, physical parameters R_c, I_c and R_p have been changed (according to the tab. 1). For both settings cases (of asthma 1 and asthma 2), all actions described for a healthy individual model were repeated. The diagnostic results of all three individuals were archived for collective visualization, which is illustrated in fig. 4.

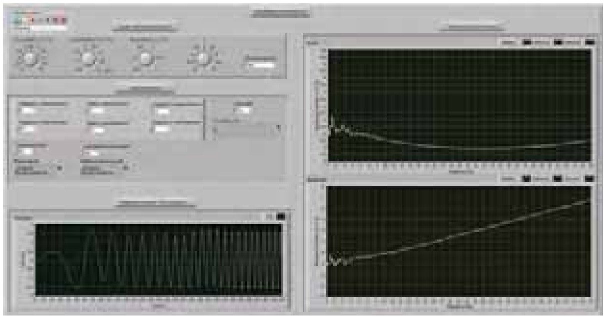

Fig. 3. User's application panel view with results of the simulation performed for a clinical case of a healthy individual

Rys. 3. Widok na panel użytkownika aplikacji wyraz z wynikami symulacji prowadzonej dla przypadku pacjenta zdrowego

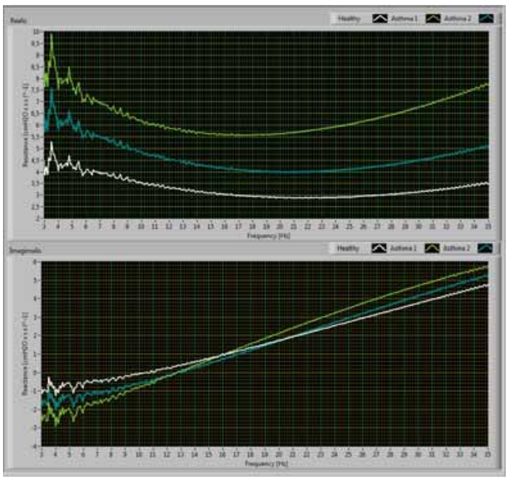

Fig. 4. Graphical results of the simulation performed for three clinical cases of various patient's health condition

Rys. 4. Wyniki symulacji przeprowadzonej dla trzech przypadków stanu zdrowia pacjenta

5. Summary and conclusions

In conclusion, designing and developing comprehensive educational applications in the field of bioengineering, can be used in both raising social awareness and improving the teaching and learning processes at all levels of education of the professionals (engineers, masters, doctors, etc.). Examples of such applications can be found in the literature [19–20]. In the future, these types of systems can also provide a foundation for intelligent systems supporting medical diagnosing and treatment. Application presented in this paper is undoubtedly a proposal of medical tool, streamlining the teaching process of detecting obstructive diseases of the human respiratory system. However, the structure of a presented educational platform allows its developers to use it in problem-oriented tasks, and in numerous and widely used e-learning systems.

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Aplikacja wspomagająca procesy edukacyjne w zakresie wykrywania chorób obturacyjnych układu oddechowego

Streszczenie: W publikacji zaprezentowano działanie platformy wspomagającej edukację w zakresie wykrywania chorób obturacyjnych układu oddechowego. Rolę badanego pacjenta pełni 16-elementowy model układu oddechowego, symulowany w środowisku MATLAB/Simulink. Został on połączony z warstwą sterowania, wykonaną w środowisku LabVIEW, przy pomocy biblioteki SIT (Simulation Interface Toolkit). Warstwa ta odpowiada za modyfikację parametrów modelu oraz generowanie wyników pomiaru impedancji układu oddechowego za pomocą oscylacji wymuszonych. Wykonana aplikacja jest rozwiązaniem zapewniającym dużą elastyczność w kształceniu studentów związanych z inżynierią biomedyczną i naukami o zdrowiu i bardzo łatwo może być wdrożona do pracy jako rozwiązanie e-learningowe, zorientowane problemowo.

Słowa kluczowe: aplikacja komputerowa, choroby obturacyjne, płuca

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