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Construction of numeric simulator of pressure, flow and volume curves in mechanical ventilators for muscular pressure estimation during the breathing cycle in patients under mechanical ventilation

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Background, Motivation and Objective. The mechanical ventilation consists in a method for the treatment of patients with respiratory insufficiency. If the equipment is not correctly adjusted it may cause serious injuries to the lungs. For an effective treatment the knowledge of resistance (R) and elastance (E) parameters is vital. During the ventilation, there are two forces that may act on the system: the pressure imposed by the ventilator and the pressure resulting from patient's muscular effort. The estimation of R and E when only the first force is present has already done, as we can find in the literature, but when both forces are present the problem is ill-posed. The objective of the current work is to develop a numeric simulator able to generate ventilation curves for the evaluation of respiratory parameters estimation algorithms in ICU patients.

Methods. The simulator development consists in three steps: (i) modelling the respiratory system; (ii) modelling the ventilator control system; and (iii) solving the model for specifics ventilation modes. For the first step a linear single-compartment model has been used. In this model the respiratory system is consisted as a Hookean elastic reservoir (lung) with elastance *E connected to the outside world via a* single channel (airways) where the air suffers a resistance to flow *R* while passing through. The tension created by the spring produces inside the compartment a pressure called elastic pressure, P_{el}, that varies linearly with the volume, *V;* and along the channel the pressure difference, ΔP, varies linearly with the flow, $\frac{dV}{dt}$. The open airways pressure, P_{ao}, is the sum of P_{el} and ΔP, $\mathrm{Pao} = \mathrm{EV} + \mathrm{R}\frac{dV}{dt}$. Is added to the equation, as a forcing term, the muscular pressure, P_m. Beside this model there are, also, a second equation in use, to represent the behaviour of the flow through ventilator tubbing, $\mathrm{aPv} = \mathrm{Pao} + \mathrm{a}\frac{d\mathrm{Pao}}{dt}$, where P_v is the pressure created by the ventilator and the constant *a* represents the resistance in the tubbing.

For the second step, a PID control is used to control P_v. For PCV mode (*pressure-controlled ventilation*) the PID error is defined as the difference between the reference pressure (P_{ao}) and measured one; and in the VCV (*volume-controlled ventilation*) the difference between the reference flow and the measured one.

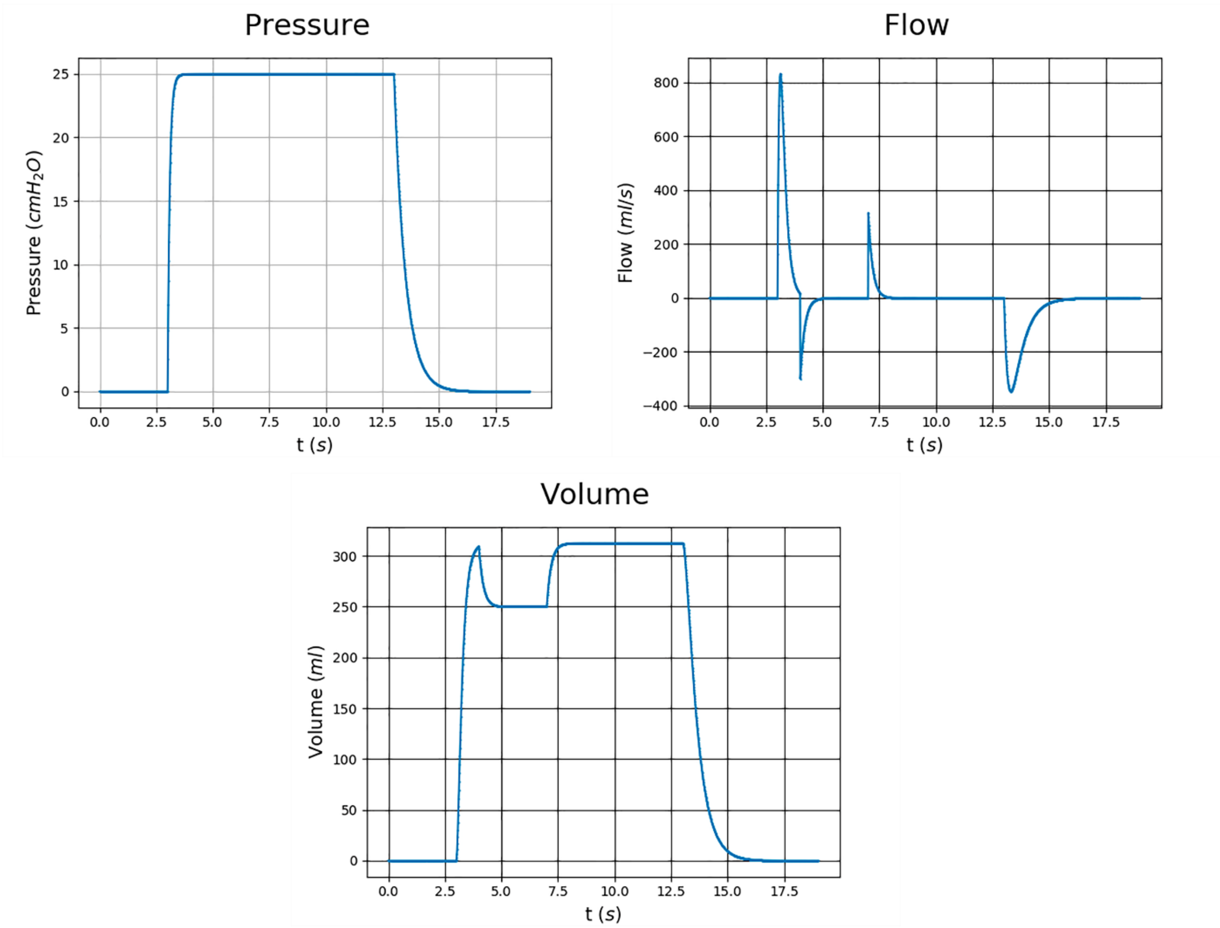
For the last step, the solving, the state-space method has been used.

Results. So far were equated and simulated single cycles in two modes, the PCV and the VCV. Was applied a negative muscular pressure (that could represent a coughing by the patient, for example) of *5* mmH_20 between $t = 4$ and $t = 7$. The system worked out just as expected, as seen in Figure 1. The control (PCV mode) maintained the pressure stable. Beside this, all the obtained curves were similar to the ideal ones in literature.

Discussion and Conclusions. The results are pretty satisfactory, through the model has been able to construct simulators that given simple but realistic curves, moving away from simulators with too idealistic curves. The next step is to start testing the estimation algorithms. First will be tested the least squares method for estimate the resistance and the elastance in situations without any muscular pressure P_m. It is hoped that with the data generated by the equations will be found approximate values to those defined earlier for the ventilation; and after that will be started studying algorithms for muscular pressure estimation, which is the mainly objective of this project.

Figures and Tables.

Figure 1. Pressure and flow curves in the PCV mode



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