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A Mathematical Model of Lung Functionality using Pressure Signal for Volume-Controlled Ventilation

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Abstract— **Mechanical Ventilation is used to support the respiratory system malfunction by assisting recovery breathing process which could result from diseases and viruses such as pneumonia and COVID-19. Mathematical models are used to study and simulate the respiratory system supported by mechanical ventilation using different modes such as volume-controlled ventilation (VCV). In this research, a single compartment lung model ventilated by VCV is developed during real time mechanical ventilation using pressure signal. This mathematical model describes the lung volume and compliance correctly considering positive end expiration pressure (PEEP) value. The model is implemented using LabVIEW tools and can be used to monitor the volume, flow and compliance as outputs of the model. Two experiments are carried out on the proposed lung model at three input scenarios of volume (400, 500 and 600 ml) for each experiment considering a PEEP value. To validate the model, an artificial lung connected to a VCV with the same scenarios is used. Validation check is conducted by comparing the outputs of the lung model to that of the artificial lung. The experimental results showed that the measured lung model outputs with negative feedback are the same for pressure and flow as the outputs without negative feedback, whereas the measured volume is comparatively lower for negative feedback. Average percent error in the experiment with negative feedback (5.14%) is smaller compared to the experiment without negative feedback (9.28%). Furthermore, the average error of the calculated compliance decreases from 16% (without negative feedback) to 2% (with negative feedback). The obtained results of the proposed method showed good performance and acceptable accuracy. Thus, the model facilitates the clinicians and practitioners as a training tool to learn real-time mechanical ventilation functionalities.**

Keywords—Mechanical Ventilation; Volume-Controlled Ventilators; Lung Compliance; Positive End Expiration Pressure (PEEP); Negative Feedback; Lung Model; COVID-19

I. INTRODUCTION

Mechanical Ventilation plays a crucial role in *intensive care unit* (ICU) for life support of patients having lung malfunction as a result of diseases such as pneumonia, COVID-19, etc. Mechanical ventilation process delivers and controls flow, pressure and volume of air and gases to a patient's lung [1]. Mechanical ventilation tries to find optimal positive end expiration pressure (PEEP) level [2, 3] and it uses real time numeric data and waveforms interpretation that helps to assess the patient response to ventilation and to maximize patient comfort and therapeutic benefits [4-6]. Commonly, there are two types of mechanical ventilation: volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) [4, 7]. Both types deliver and control flow, pressure and volume of air and medical gases to the patient's lung. VCV is commonly used to treat disordered lungs, delivering constant volume to patient's lung [8].

Mathematical models provide realistic solutions for complex engineering problems [9-12]. A mathematical model can be used to describe patient's lung mechanics. Furthermore, models are developed to optimize mechanical-ventilation therapy. Many studies use a single compartment lung model that can describe lung elastance (1/compliance) and air way resistance [13-15]. The model incorporates lung volume and air flow, as well as PEEP that exerts additional pressure at the end of expiration to reduce alveoli collapse, and reduces the risk of lung damage [3, 16]. In addition, in some cases, PEEP is important to reduce work of breathing. Moreover, titrating PEEP is important during mechanical ventilation to optimize lung characteristics [16, 17]. However, excessive increase in PEEP which adds extra volume can cause ventilator induce lung injury syndrome [18].

Most of the previous works recorded (pressure and flow) signals as input data to validate single compartment model [14, 19, 20]. This study aims to optimize and validate a single compartment lung model supported by VCV through applying one input signal (i.e., pressure) during real-time mechanical ventilation to describe lung volume and compliance correctly [21, 22]. In real practice of VCV, the lung volume should remain constant even in change of pressure [8]. Adding PEEP in the lung model results in increase of lung model output volume, and affects the compliance [23-26].

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