Fuzzy control of tidal volume for ARDS patients in closed-loop ventilation

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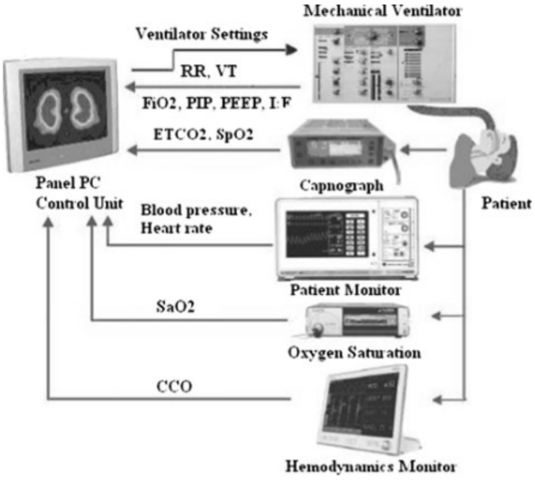
Introduction

Patients with Acute Respiratory Distress Syndrome (ARDS) face a partial lung collapse caused by inflammation of lung parenchyma leading to an impaired gas exchange and may subsequently experi- ence multiple organ failure. It is a life-threatening syndrome with a mortality rate between 15 and 72 % [1]. The syndrome can be treated by using an artificial ventilator with proper strategies, for example, Open Lung Concept (OLC) or ARDSnet protocol with the goal to improve gas exchange for optimal oxygenation and better carbon dioxide elimination. Providing a knowledge base of medical experts, the realization of automated artificial ventilation system is achievable using a fuzzy based expert system for treatment of patients with ARDS. Based on Open Lung Concept or ARDSnet under pressure control mode, a low tidal volume e.g. 6 ml/kg needs to be regulated and applied to the patients after the recruitment maneuvers in order to



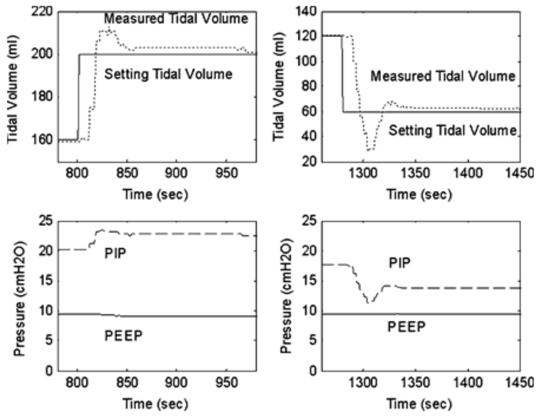


Fig. 2 Tidal volume control based on a fuzzy controller with PEEP = 10 cmH_20, RR = 30 bpm and I:E = 1:1

Fig. 1 System configuration of fuzzy based medical expert system in closed-loop ventilation

avoid hyperventilation, to minimize the mortality rate and to prevent ventilator associated injuries of the lung.

Methods

The closed-loop medical expert system named VENTILAB [2], which has been developed at RWTH Aachen University, consists of 3 main subsystems: Panel PC Control Unit (PPC-154T), mechanical venti- lator (Servo 300, Siemens Elema) and measuring devices, for example, capnograph (CO2SMO?, Respironics, Inc.), Patient Mon- itor (Sirecust 960, Siemens) or spectrophotometry (CeVOX, Pulsion Medical System) (Fig. 1).
The physiological parameters are measured from the measuring devices and sent to the panel PC for further analysis and making a decision for the automatic adjustment of the ventilation settings. After an 'Open Lung' recruitment maneuvers [3], a low tidal volume is introduced to the patient and only Peak Inspiratory Pressure (PIP) and Positive End-Expiratory Pressure (PEEP) would have an impact to the control of tidal volume because other parameters are kept constant. Therefore, this system can be simplified as Single-Input and Single- Output by a consideration of the driving pressure (DP = PIP-PEEP), as a control signal for achieving the determined tidal volume.
The inputs of fuzzy controller are tidal volume error (ei = VTset(i) - $VT_{measured}$ (i)) and the difference of tidal volume error (Δe = e(i) – e(i-1)) between breaths. The linguistic labels are Negative Large (NL), Negative

Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM) and Positive

Table 1 Rule basis for fuzzy controller

Δe	NB	NM	NS	Z	PS	PM	PB
e							
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Large (PL). A rule base is a set of IF-THEN rules, which are con- solidated in Table 1.

Result

Some experiments are carried out using a mechanical lung simulator with a fixed PEEP at 10 cmH2O and its result of automatic adjustment of PIP is shown in Fig. 2, which also demonstrates the performance of fuzzy controller in regulating the tidal volume. The measured tidal volume can be regulated to the requested tidal volume with accept- able range of error (within 5 ml) that may be caused by the disturbance, measurement uncertainty and time-varying property of lung mechanics.

Discussion

The fuzzy control algorithm is capable of automatically regulating the tidal volume of the patients after an 'Open Lung' recruitment maneuvers or an ARDSnet strategy under pressure control mode. As a result, it can be integrated into the software as an algorithm for tidal volume control for better protective ventilation to the patients with ARDS.

References

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