Automatic Control of Artificial Ventilation Therapy

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Master of Science (Engineering)
Anake Pomprapa
aus Bangkok, Thailand

Berichter: Univ.-Prof. Dr.-Ing. Dr. med. Steffen Leonhardt
Prof. Dr. Dr. med. Burkhard Lachmann
Univ.-Prof. Dr.-Ing. Stefan Kowalewski

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Anake Pomprapa

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The Lord God formed the man from the dust of the ground
and breathed into his nostrils ***the breath of life***
and the man became a living being.
Genesis 2:7, New International Version

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Anake Pomprapa, M.Sc.(Eng), MCS
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Abstract

A dysfunction of the pulmonary system triggers an impaired gas exchange with severe progressive hypoxemia and hypercapnia. In this work, the abnormal breathing sounds are primarily acquired by a newly set-up electronic stethoscope based on pig models and analyzed with a Wavelet-denoising filter and Hilbert-Huang transform. This is implemented for the feature extraction to classify the abnormal lung sounds in terms of timing and the corresponding visual representation of instantaneous spectrum, respectively. With these quantitative affirmations, crackles are detectable in the established computerized auscultation system at the bedside. This unveils the unique pathophysiological effect of the respiratory system in time and frequency domains associated with the proposition from the American Thoracic Society.

In intensive care medicine, the therapeutic approach is mainly based on the institution of mechanical ventilation. To gain an insight into the impact of ventilation variables upon carbon dioxide (CO_2) elimination, a mathematical model has been developed as a nonlinear function of driving pressure, temporal settings, lung mechanics and metabolic rate based on a single-compartment model. The percent of inspiratory time (%TI) has been incorporated in the model of CO_2 elimination for the first-time. Thus, this provides a valuable clinical application in ventilation adjustments for hypercapnia therapy with a validation of porcine dynamics, which, owing to the unequal airway resistances during inspiration and expiration, is an optimal setting of %TI and can furthermore enlarge CO_2 elimination.

Since gas exchange of oxygen and CO_2 is the prime essence of the respiratory function, a closed-loop and embedded ventilation system is set up with a Controller Area Network protocol for data communication based on an ARM microcontroller. It also uses MATLAB with Simulink and ControlDesk software under a MicroAutoBox II dSPACE platform for implementing the control algorithms and the user interface. System identification is carried out for characterizing model structures and model order with a least squares algorithm for the non-invasive control of end-tidal CO_2. Using an advanced model-based approach, robust $\mathcal{H}_\infty$ loop-shaping and $\mathcal{L}_1$ adaptive control systems were designed and their closed-loop performances was simulated. In addition, quasi non-identifier approaches of the non-linear time-varying respiratory system, i.e. funnel control and policy iteration algorithm, were implemented by simulations of the control of oxygenation. The distinctive results of gas exchange control are then achieved based on the proposed control algorithms with noninvasive measurements.

Ultimately, automatic control of an artificial ventilation system was configured in a star topology integrating the closed-loop hemodynamic control of mean arterial blood pressure by noradrenaline infusion. The overall multitasking with a goal-oriented structure was coded with LabVIEW graphical programming and FuzzyTECH software for the patients with acute respiratory distress syndrome in another development platform, called "Ventilab". The closed-loop fuzzy expert system can actively and intelligently perform a long-term treatment with two different protocol-driven ventilation strategies, namely standardized automatic Acute Respiratory Distress Syndrome Network (ARDSNet) protocol and innovative automatic Open Lung Management® based on arterial oxygen saturation.

The former concept focuses on three main goals, namely the stabilization and regulation of oxygenation, plateau pressure and blood pH, while the latter seeks extremal pressures for recruitment maneuvers and for proper ventilation related to the open lung concept, provides protective ventilation, controls CO_2 exchange with a fuzzy controller and periodically reduces the positive end-expiratory pressure. Both developed algorithms have high potentials for being integrated into a commercial system and are potentially applicable for individuals as a generalized solution for clinical ventilation. Based on porcine models with surfactant wash-out by repetitive lung lavages, the algorithmic performances were assessed by biochemical properties of standard arterial blood gas analysis, mechanical properties of the setting ventilation variables, and the pathophysiological change non-invasively measured by real-time electrical impedance tomography.

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