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Model-based Optimization of Ventilator Settings for Bedside Application

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Abstract: *Mechanical ventilation is a life-saving therapy on intensive care units but has the risk of deploying additional pulmonary trauma due to non-personalized ventilator settings. Mathematical models can be used to derive individualized settings.*

Such an approach was implemented on a tablet computer receiving real-time data from a mechanical ventilator to compute model-based ventilator settings.

Therefore, a mobile application displays real-time data measured by the mechanical ventilator and calculates suggestion of optimized ventilator settings in terms of minimal inspiration pressure and sufficient expiration time to be directly applied at the ventilator in pressure controlled ventilation. With such an application, alveolar stress and the risk of intrinsic PEEP could be reduced directly at the bedside.

Keywords: *Android Systems, Mechanical Ventilation, Data-Communication*

Introduction

Mechanical ventilation carries the risk of ventilator-induced lung injury (VILI), mainly caused by excessive stress on lung tissue [1]. To minimize the risk of VILI, ventilator settings should be personalized according to the individual patient's physiology [2]. A recently developed model-based algorithm visualizes the nonlinear patient-specific relation of ventilator settings to meet a defined minute ventilation (MV) [3]. The algorithm requires real-time measurements of respiratory mechanics for model individualization to calculate optimized settings in terms of minimized inspiration pressure (p_I) and sufficient expiration time (t_E). Thus, un-physiological stress on lung tissue can be minimized and the risk of intrinsic positive end-expiratory pressure (PEEP) is reduced. To apply this application at the bedside, this paper presents an approach to implement this algorithm on a tablet computer for increased practicability.

Methods

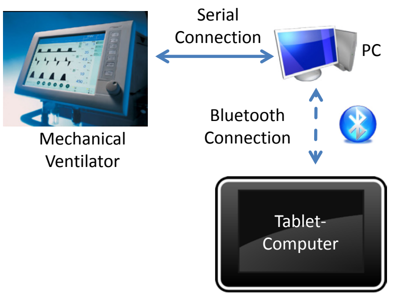

Figure 1: Communication concept between the mechanical ventilator and a tablet computer

Hardware Setup

The mechanical ventilator (EvitaXL, Dräger medical, Lübeck) is connected via a serial connection to a computer bridging the connection to a tablet computer (Motorola XOOM, Android 4.04) via Bluetooth (Figure 1).

Software Concept

The computer runs a LabVIEW application and provides a Bluetooth – port (*Open_Port*) for serial communication between tablet and PC. Secondly, the LabView-Application initiates and terminates the communication between PC and mechanical ventilator (*Start_Communication, Stop_Communication*) and transfers the status of the communication to the tablet. A *Get_Data* command requests ventilation information being the patient's resistance (R), compliance (C), expiratory time constant (τ_E) and applied PEEP measured by the mechanical ventilator. *Get_Data* packs the information into a protocol and forwards it to the tablet. The *Get_Stream* command receives real-time measurements from the mechanical ventilator of airway pressure, flow rate and volume sampled at 125 Hz. The communication between PC and mechanical ventilator is based on manufacturer specific commands implemented in a provided DLL using the MEDIBUS protocol (Dräger Medical, Lübeck).

The Android-based application was developed using Android SKD. When starting the application, the user is asked whether a Bluetooth connection should be established or an offline mode is preferred. The Bluetooth connection is established by sending the *Start_Communication* command to the PC. Afterwards the user can request ventilation information of R, C, τ_E and PEEP for a subsequent optimization of ventilator settings. Secondly, real-time data can be requested to be handled in a service running in the background of the Android system. The received real-time data can be dynamically plotted in a separate tab (Fig. 2). Additionally, the data stream can be locally saved on the device for a subsequent analysis in the offline-mode. In this mode, the file with previously recorded data can be opened to proceed for additional planned offline analysis. This function offers the possibility to simulate an input stream without heaving a Bluetooth connection.

Optimizing ventilator settings: Patient-specific respiratory mechanics information of R, C and τ_E can either be obtained by the mechanical ventilator (*Get_Data*) or by an online model-identification using the real-time data. R and C can be determined by identifying the 1st order model of respiratory mechanics (FOM) to measurements of flow rate and airway pressure. τ_E is estimated by fitting an exponential function to the flow signal during expiration. Incorporating R, C and τ_E leads to the nonlinear relation between p_I and t_I to reach a preset minute ventilation (MV) during pressure controlled ventilation (PCV) with $t_E = 3 \cdot \tau_E$ [3]:

$$p_I = \frac{MV(t_I + 3\tau_E)}{C\left(1 - e^{-\frac{t_I}{RC}}\right)} + PEEP \qquad (1)$$

Results

Figure 2 shows dynamic plotting of airway pressure, flow rate and volume of a test lung being ventilated in pressure controlled ventilation mode.

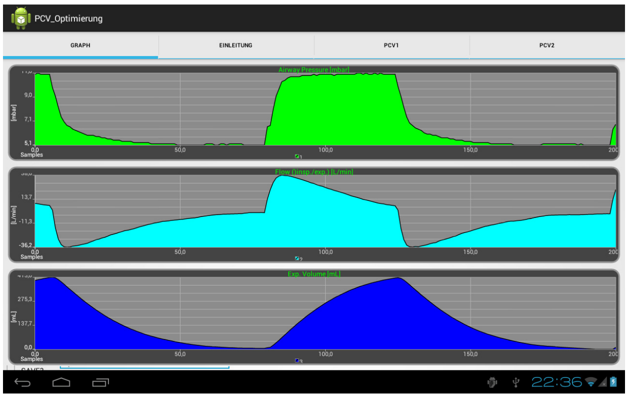

Figure 2: Dynamic plotting of real-time data (Top: Airway Pressure, Middle: Flow Rate, Bottom: Volume)

With specific respiratory mechanics properties of R = 10 cmH_2O/L, C = 40 mL/cmH_2O and τ_E = 1 s a minute ventilation of 6 L/min can be obtained with the settings illustrated in Figure 3. These suggested ventilator settings could be immediately set at the mechanical ventilator to achieve the desired target MV.

Discussion

The presented application allows deriving model-based patient-specific ventilator settings on a mobile platform directly at the bedside. The settings minimize the inspiration pressure to reduce alveolar stress and provide a sufficient expiration time to avoid the risk of intrinsic PEEP.

In the future, additional models of respiratory mechanics and gas-exchange will be considered to include blood gases in the optimization process to obtain FiO2 settings. Additionally, the software architecture will developed towards improved practicability and efficiency by distributing extensive computation tasks such as model simulation and identification to the PC.

The possibility of providing individualized, optimized ventilator settings on a mobile device improves practicability for the clinician to achieve their therapeutic goals fast and easy directly at the bedside.

Figure 3: Left: Defined minute ventilation (MV) and PEEP. Patient-specific respiratory mechanics (R, C and τ_E). Middle: pI as a function of tI (Eq. 1). Right: Calculated optimized ventilator settings at the minimal point of p_I.

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