Adaptive pressure control applied to mechanically ventilated patients

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Mechanical ventilation

Mechanical ventilation is used in Intensive Care Units (ICUs) to save lives of patients unable to breath on their own. Mechanical ventilation supports patients by ensuring adequate oxygenation and carbon dioxide elimination [1]. A schematic representation of a blower-driven mechanical ventilator attached to a patient is depicted in Figure 1. The system consists of a blower generating flow and pressure profiles, the hose-filter system, and the patient.

Relevant control problem

The control goal is to achieve accurate tracking of the patient airway pressure p_{aw}, i.e., $e = p_{target} - p_{aw}$ should be small with p_{target} the desired airway pressure. In commercial systems, unit feedforward with a linear feedback controller is used to achieve adequate tracking performance of p_{aw}. The feedback controller has to compensate for the pressure drop over the hose $\Delta p = p_{aw} - p_{out} = R_{lin}Q_{out}$. Moreover, the feedback controller is designed to ensure stability for a wide variety of patients, hence, performance is far from optimal. Predicting this pressure drop a priori is challenging, since it depends on several unknown factors:

- the patient, i.e., lung and airway, that is ventilated;
- the characteristics of the hose-filter system;
- (un)intended leakage in the system;
- spontaneous breathing activity of the patient.

Therefore, a controller is desired that accurately compensates for this pressure drop, and achieves accurate tracking of p_{target}. This controller should fulfill the following requirements:

- improve tracking performance, independent of the described unknown factors;
- handle time-varying system parameters;
- prevent overshoot in patient flow and therewith false ventilator induced triggered breaths;
- avoid using direct feedback on the patient airway pressure, p_{aw} sensor might come loose in practice.

Control approach

To improve tracking performance, an adaptive control approach is developed that compensates for the pressure drop Δp over the hose. This control approach uses the measured flow Q_{out}, and pressures p_{aw} and p_{out} to estimate the linear resistance of the hose R_{lin}. A recursive least squares algorithm is developed, see [2], to obtain the linear resistance

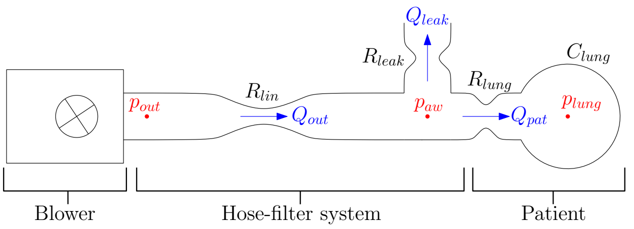

Figure 1: Schematic overview of the blower-hose-patient system.

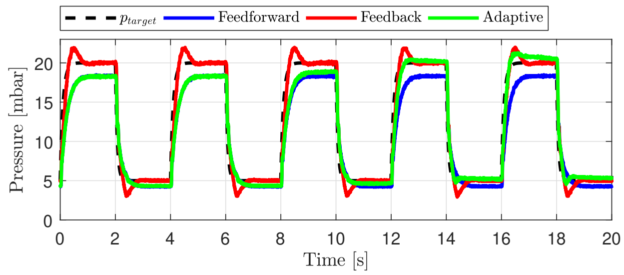

Figure 2: Experimental results comparing different control approaches.

estimate $\hat{R}_{lin}$. Using the estimate $\hat{R}_{lin}$ and the measured flow Q_{out}, an estimate of the pressure drop $\Delta\hat{p} = \hat{R}_{lin}Q_{out}$ is used to compensate for the actual pressure drop. A stability result is derived that shows exact tracking of a time-varying reference, whilst ensuring all requirements and handling the unknown factors.

Experimental results

Through an experimental case study the improved tracking performance is shown, see Figure 2. The figure shows an improvement in tracking performance compared to feedback control, specifically, the undershoot has decreased. This improvement prevents overshoot in the patient flow Q_{pat}, improving patient comfort and consistency of treatment.

Further improvements could be achieved by considering a quadratic resistance model and/or the delays in the system in the scope of controller design.

References

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