Master's Thesis

Nonlinear Control of an Anesthesia Device

Project Background

Control in anesthetic devices enjoys an ever-growing importance due to a trend to support the anesthetist with the aim of allowing more time to focus on other complex tasks. The complexity of anesthesia itself also demands automation.

Anesthesia is composed of three desired reversible effects: Elimination of pain (analgesia), paralysis of muscles (relaxation) and lack of consciousness (hypnosis). These effects can be induced either by intravenous or volatile anesthetic agents. Volatile anesthetics are mixed into the breathing gas during mandatory mechanical ventilation, which is required due to the artificially induced relaxation.

Based on prior work on the modeling of an anesthetic device, the goal of the thesis is to design an improved control algorithm for the concentration of the administered volatile anesthetics. A pharmacokinetic/pharmacodynamic model of a patient [3] can be incorporated for controlling end-tidal concentrations of anesthetic agents and for performing a simulation study with regard to hypnotic and analgesic effects. End-tidal gas concentrations correlate well with the concentrations of the anesthetic agents in the lung. A reference for the desired concentration is given by the minimal alveolar concentration, which is an indication of the absence of reflexes to pain induced stimuli in about 50% of the patients.

The considered anesthetic device is designed as a rebreathing system. Parts of the expired gas is reconditioned by absorbing CO2 and still contains sizable amounts of anesthetic agents. The amount of fresh anesthetic agents required in the fresh gas flow during each breathing cycle is therefore reduced. However, this requires a constant tracking/estimation of the gas concentrations in the inspired gas and control algorithms to maintain desired set points.

The dynamic model of the concentration dynamics inside the anesthesia device can be separated into inspiratory, expiratory as well as the rebreathing branch. Relevant dynamic effects consist of variable time delays due to gas transport and nonlinearities due to the inherent multiplication of volume flows and concentrations in the governing differential equations. The coefficients of the pharmacokinetic model are mostly based on empirical values, but also depend on the minute volume applied to the patient. These nonlinear effects due to parameter variations can be embedded in the so-called linear parameter-varying (LPV) framework, in which a system is represented as a linear system with time-varying parameters [1]. These parameters can depend on system states and thus represent, e.g., nonlinear coupling, stiffness or damping effects. Due to the embedding of nonlinearities in an essentially linear model structure, many tools originating from linear systems estimation and control have a relatively straightforward extension to LPV systems, which is hence an attractive class of models.

The application of the LPV framework to anesthesia control to derive a compact and tractable nonlinear system representation on the basis of which controllers can be efficiently designed and tuned is a novel approach. The project promises to yield a highly systematic benchmark result in showcasing achievable performance with modern tools from control

Project Description
In this thesis project, the modeling algorithm proposed in [2] will be extended to cover a wider class of LPV systems.

Tasks

- Familiarization with LPV systems in linear fractional representation
- Generalize the system identification algorithm to incorporate
    - Affine LPV systems with fully unknown low-dimensional system structure
    - Rational LPV systems in linear fractional representation
    - Scheduling parameters depending on estimated states
- Modification of the system identification algorithm to the estimation of scheduling parameters
- Empirically convergence and simulation studies
- Application to relevant simulation models

References
[1] Wu, Fen (1995): Control of Linear Parameter Varying Systems. Ph.D. Thesis. University of Berkeley, California, USA. Mechanical Engineering.

[2] Hoffmann, Christian (2016): Linear Parameter-Varying Control of Systems of High Complexity. Ph.D. Thesis. With assistance of Herbert Werner, TUHH Universitätsbibliothek. Germany: TUHH Universitätsbibliothek (electronic publication), Dr.-Hut-Verlag (print publication). Available online at http://tubdok.tub.tuhh.de/handle/11420/1304.

[3] James M. Bailey. The pharmacokinetics of volatile anesthetic agent elimination: A theoretical study. Journal of Pharmacokinetics and Biopharmaceutics, 17(1):109–123, February 1989.

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