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Document name
DOCTORATE THESIS

Date of issue
September 2013

Document Number
ISRN LUTFD2/TFRT--1096--SE

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Sponsoring organisation
The Swedish Research Council through LCCC

Title and subtitle
On Automation in Anesthesia

Abstract

The thesis discusses closed-loop control of the hypnotic and the analgesic components of anesthesia. The objective of the work has been to develop a system which independently controls the intravenous infusion rates of the hypnotic drug propofol and analgesic drug remifentanil. The system is designed to track a reference hypnotic depth level, while maintaining adequate analgesia. This is complicated by inter-patient variability in drug sensitivity, disturbances caused foremost by surgical stimulation, and measurement noise. A commercially available monitor is used to measure the hypnotic depth of the patient, while a simple soft sensor estimates the analgesic depth. Both induction and maintenance of anesthesia are closed-loop controlled, using a PID controller for propofol and a P controller for remifentanil. In order to tune the controllers, patient models have been identified from clinical data, with body mass as only biometric parameter. Care has been taken to characterize identifiability and produce models which are safe for the intended application. A scheme for individualizing the controller tuning upon completion of the induction phase of anesthesia is proposed. Practical aspects such as integrator anti-windup and loss of the measurement signal are explicitly addressed. The validity of the performance measures, most commonly reported in closed-loop anesthesia studies, is debated and a new set of measures is proposed. It is shown, both in simulation and clinically, that PID control provides a viable approach. Both results from simulations and clinical trials are presented. These results suggest that closed-loop controlled anesthesia can be provided in a safe and efficient manner, relieving the regulatory and server controller role of the anesthesiologist. However, outlier patient dynamics, unmeasurable disturbances and scenarios which are not considered in the controller synthesis, urge the presence of an anesthesiologist. Closed-loop controlled anesthesia should therefore not be viewed as a replacement of human expertise, but rather as a tool, similar to the cruise controller of a car.

Key words
PID control, medical applications

Classification system and/or index terms (if any)

Supplementary bibliographical information

ISSN and key title
0280–5316

ISBN
978-91-7473-484-3

Language
English

Number of pages
136

Recipient's notes

Security classification