Doctoral Dissertation
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Smart Electronic Pen for Continuous Monitoring of Anaesthetics

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Summary

General anaesthesia is a challenging medical procedure inducing a reversible state of unconsciousness in patients during surgery to facilitate operations. The sedation is achieved by infusion of a perfectly balanced cocktail of pharmacological compounds. The delivery rate of this cocktail has to be continuously monitored to achieve and maintain the desired level of sedation to avoid complications and side effects related to over-dosage or under-dosage. Today, PharmacoKinetics and PharmacoDynamics (PK/PD) models regulate, via Target Controlled Infusion (TCI) pumps, the delivery of anaesthetics, and the patient is continuously monitored via BiSpectral (BiS)-index, a weighted sum of ElectroEncephaloGraphic (EEG) features. This approach comes with some limitations since PK/PD models are only statistically accurate since they are experimentally derived from observation on a population of individuals, and EEG suffers from measurement artifacts.

To overcome these limitations, we proposed to close the loop between anaesthesiologist and patient with Therapeutic Drug Monitoring (TDM). Continuous monitoring of anaesthetics infusion helps anaesthesiologists to define personalized dose towards safer surgery. This thesis presents a newly required different part of the system to keep under control the concentration of anaesthetics in the body of the patient, which it was missing up today: the smart electronic pen for continuous monitoring of anaesthetics. Namely, the pen includes in a single device a unique electrochemical sensor, leveraging on new measurement methods, in a custom embedded device. The sensor built is a needle-shaped electrochemical cell fully characterized for direct detection of anaesthetics (propofol) in undiluted human serum. Several methods are specially developed in this thesis, including Sampling Rate Optimization (SRO), Total Charge Detection in Cyclic-voltammetry (TCDC), and Propofol Fouling Machine-learning (PFM) smart processing. The proposed device is a battery-operated single Printed Circuit Board (PCB) with wireless communication. It includes a novel quasi-digital potentiostat in a pen-shaped case for easy use in the surgery room.

The proposed smart electronic pen achieves the four primary goals as required towards a closed-loop system for TDM of anaesthetics: portability, real-time detection, automatic smart processing, and continuous monitoring. The developed technology is low-power, wireless, and small size compared to the state-of-the-art to facilitate mobility into the surgery room. The system provides real-time detection with the first needle-shaped propofol sensor. Moreover, and for the first time in this work, machine learning approaches successfully compensated non-linearities of the electrochemical sensor, allowing smart processing. Finally, the sensor, methods, and electronics introduced in this thesis allow continuous monitoring of anaesthetics.