Verschiedene Konzepte zur Regelung der Herz-Lungen-Maschine

Different Concepts for Controlling the Heart-Lung-Machine

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Purpose

Extracorporeal perfusion is the standard technique in cardiac surgery. It is controlled by perfusionists on the basis of their clinical experience and on the available data collected pre- and intra-operatively. In order to reduce postoperative complications, a mathematical model of a human circulatory system has been developed which provides much more information about haemodynamics, blood gases and acid-base status than standard monitoring. It has been implemented on a system which is capable of integrating measured data as input parameters in real-time in the simulation. An appropriate control of the Heart-Lung-Machine (HLM) using an "autopilot" might improve the quality of heart-surgery and decrease postoperative complications. In this paper, different control concepts based on the model of the human circulatory system are introduced.

Material and Methods

During the last years a mathematical model of the human circulatory system has been invented, which is able to estimate the haemodynamics and additionally provides information about blood gas parameters in real time. With this new kind of information system, an automated control of the Heart-Lung-Machine is considered. This control system must be able to maintain

- the arterial pressure,
- the oxygen supply,
- an accurate blood temperature and a
- reduction of carbon dioxide.

This can be achieved by varying

- the blood flow,
- the oxygen content of the gas flow,
- the water temperature of heater-cooler-device and
- the gas flow of the oxygenator.

Many kinds of control mechanism are applicable. In this paper we compare three different kinds of control strategies:

- PID
- State Space Control
- Model Predictive Control (MPC)

The PID control design is one of best known, because of its simple structure. This controller always compares the actual value against the set value and provides a correction value. Ziegler and Nichols provides a routine for estimating the controller properties.

The State Space Control requires a internal model of the plant comparable to a Luenberger Observer. Therefore the plant has to be linearised and transferred into state-space. This transformation gives additional information about the system dynamics.

The MPC calculates the optimal control variable in advance. Therefore it requires future process information. This is achieved by using a recursive least-squares estimator to make an online identification of the process.

Results

Different control concepts have been implemented and tested in Matlab / Simulink environment. The model of the human circulatory system has been used as plant. All three controller designs are able to maintain the assigned parameters. The PID controller is very fast because of its simple design, but has trouble dealing with oscillations. The State Space Control also provides good results, but because of complex design, real time is not (yet) available. The preferred controller is the MPC, not because it provides the best results but it is also universally applicable.

Conclusion

The simulations provides good results with the tested control concepts. Which kind of controller is used depends on the calculating capacity and the robustness required.