

# Model based control for modern dialysis

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**M**odern dialysis machines are becoming more and more complex in order to offer a better quality of care. Meanwhile the increasing amount of new features adds to the overhead time and extends the time between treatments. This effect can be counteracted by using more advanced controllers.

## Background

Adding more components to machines means more connections. In the dialysis machine this entails to more tubing, more tubing leads to longer time delays and longer time delays leads to slower start-up of all feedback control systems. The longer treatment means it's more costly for the care giver and more cumbersome for the patient. At three treatments per week, four hours each and one hour in between makes dialysis an expensive treatment for everyone involved. That's why it's also important to develop faster controllers and better algorithms.

## Problem statement

One of the slowest processes in a dialysis machine is the concentrate control. The concentrate controller is responsible for adding electrolytes and pH buffer to the dialysate which is used in the filtering process. The feedback for this process is measured as the change in conductivity but the placement of the sensors is further down the fluid path and is thus delayed by a few seconds. In between a set of mixing chambers are used to even out irregularities and their volumes are quite large relative to the flow. This relation means that the time constants of the system are quite large.

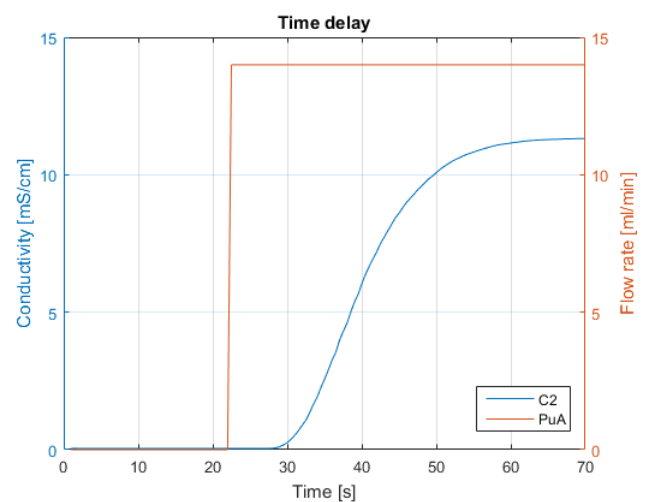


Figure 1: Time delay seen in the step response

## Modelling

In order to increase the performance of the system, knowledge of the process is needed. This is referred to as modelling. By creating a model of the specific process we can obtain knowledge that helps in the design of the controller algorithm by allowing for external simulations of the process and also creating a controller based on the model i.e., a model based controller.

There are two general ways of obtaining a model, one is by physical modelling and the other is empirical modelling.

### Physical modelling

Physical modelling is the procedure of identifying the underlying differential equations that describe the process. The differential equations are related

to the physical variables that affect the states of the process.

As an example the change of concentration in a container can be described by the difference in the injected concentration and extracted concentration. This differential equation can be seen in Equation 1

$$V \cdot \dot{C} = C_{in} \cdot q - C \cdot q \quad (1)$$

$V$  is the container volume,  $q$  is the flow rate,  $C$  is the current concentration and  $C_{in}$  is the injected concentration.

## Empirical modelling

An empirical model is a kind of model that is generated by a computer using measurements from the process. There are a lot of different algorithms for empirical modelling and they are suitable for different applications but in general they all require some prior knowledge of the process. The empirical model doesn't have states related to physical variables as a physical model.

## Comparison

By simulating both models and comparing them to the process output we can find the most suitable model. In Figure 2 a comparison can be seen, where the normalized square error shows the similarities as a percentage.

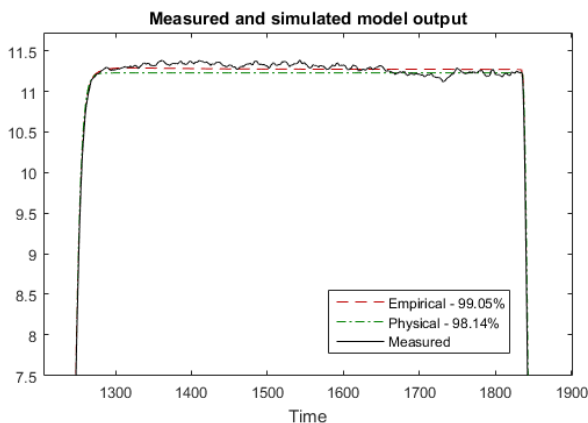


Figure 2: Comparison of different methods

## Controller

When a suitable model is identified, a controller that can take advantage of such a model is needed. There are a lot of different controller algorithms ranging from extremely simple to more advanced types. Figure 3 shows a comparison in simulations

of the different controllers where three alternatives have been compared.

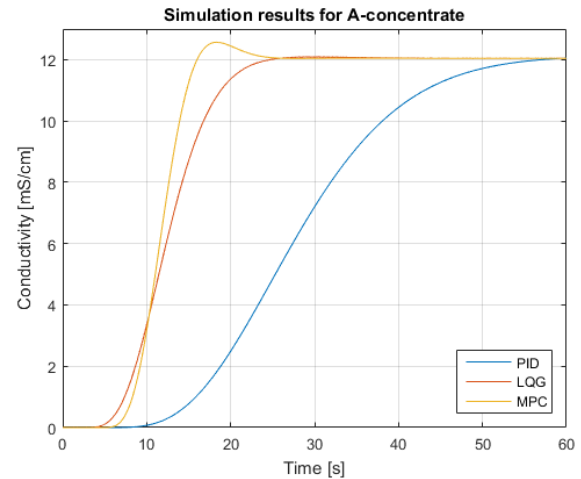


Figure 3: Comparison of different controllers

The three different controllers are ranging from simple to advanced in respective order. The results indicate that a gross speed-up can be achieved by using a more advanced controller.

## Conclusion

From the results obtained in the simulations one specific type of controller was deemed most suitable as it had good performance and it wasn't the most computationally heavy algorithm.

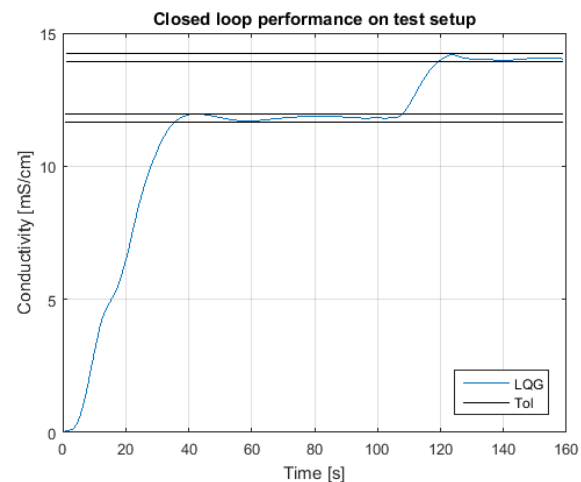


Figure 4: Closed loop performance of the proposed controller

The proposed controller is shown in Figure 4, where two types of concentrates are tested successively with a short break in between as a safety check.