CARINTHIA UNIVERSITY OF APPLIED SCIENCES

FACHHOCHSCHULE KÄRNTEN

Carinthia University of Applied Sciences

Degree Program: Systems Design

EXTRA QUESTIONS

"Control Systems Special Topics 1"

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1.3 FLS

Question: MFs for inputs; zero MF is for both input variables and output variable is very narrow. Is there any special reson for this?
The controller tries to regulate the position of the rod to $\theta = 0$, as this angle is defined as the unstable equilibrium point. The consequence of this is, that a larger region for the *zero* MF would most likely lead to a position error of the closed loop system. To minimize this error, the MF was chosen to be very narrow. Furthermore, a larger region would reduce the speed of the controller, because the rules, which depend on the *zero* MF, would decrease the output torque.

Question: Which operators do you use in your FLS (min/max or +/). Do you think the results would change if you change the sets of operators?*
The implemented fuzzy logic controller uses the *min* method as and method and *sum* for the aggregation. A change in these methods results in small changes, but the overall system behaviour would most likely be similar. The reason for this is, that only two input variables are used, therefore only one "and" is possible per rule. Also the number of rules is also very low, therefore the influence of the aggregation method is also very low.

Question: How did you decide about the area which should be covered by MFs for torque?
The needed torque, to overcome the gravitational force, is approximately 10 Nm. For a faster upswing, the needed value was multiplied by the factor three. Furthermore, as the amount of the MFs for the output torque was kept low with five functions, only two MFs remained for the positive and the negative side. As the maximum torque is only needed to drive the rod upwards, the outer MFs, *BN* and *BP* respectively, were chosen with a width of approximately 10 Nm. This means, that for the MFs *N* and *P*, the range from approximately ± 20 Nm to 0 Nm had to be covered.

3.2 ANN toolbox

Question: Could we implement this toolbox to solve the problem which we had in our controller where we had estimation learning? Please explain your answer.
Basically, with a large amount of training data, it would be possible to get suitable results. The problem is, that a very large amount of training sets is needed to get a fine approximation. Also, as no online learning is provided, the neural network could not react to disturbances or changes of the system, as the weights are fixed after the design of the NN. Therefore, the results would most likely be very different, compared to the self designed NN with the backpropagation learning algorithm. Also, if not enough training data is used for the learning process, unwanted behaviour, like a position error, or even an unstable closed loop system might occur.

4.2

Question: You are mentioning also trapezoidal, the exponential or the constant velocity profiles. Could you describe them shortly?
The trapezoidal velocity profile has a constant acceleration at the beginning. This leads to a linear rising velocity and a parabolic rise of the position. Afterwards, the acceleration is reduced to zero, leading to constant velocity and a linear change in position. At the end, the acceleration is again constant, with different sign from the beginning, to reduce the velocity back to zero.
The constant velocity profile has, as the name suggests, a constant velocity value and therefore

a linear change in position. Changes in velocity are always done stepwise, which leads to a very high acceleration. This profile is very easy to implement, but cannot be applied, if a reference acceleration is needed.
The exponential velocity profile uses an exponential function as basis for the creation of the velocity. As this results in an continuous differentiable velocity, the acceleration can easily be calculated by deriving the velocity. The position is shaped like a s curve.

4.3

Question: It is written 'The output of the network is the approximated system', page 26. Please explain this in more details; what exactly is approximated by NN?
The NN approximates the function $\mathbf{f}(\mathbf{x}) + \Delta\mathbf{B}(\mathbf{x})u + \mathbf{d}(\mathbf{x})$, where $\mathbf{f}(\mathbf{x})$ is the nonlinear function vector, $\Delta\mathbf{B}(\mathbf{x})$ is the unknown/changing part of the input vector, which in this case contains the moment of inertia, and $\mathbf{d}(\mathbf{x})$ is the disturbance vector. This means, the NN approximates the system dynamics, the uncertainties of the moment of inertia and the disturbances applied to the system.

Question: Please explain how did you set parameter M.
The mass of the cylinder is given with 0.05 kg and the radius of the cylinder is 0.04 m. The moment of inertia for a cylinder rotating around its centre point can be calculated with $\frac{1}{2}mr^2$. For this system, this results in a moment of inertia of $40 \cdot 10^{-6}$ kg m^2. As this value is only an estimation and the NN is used to approximate the unknown part of the moment of inertia, the used value can be chosen somewhere in this region. Furthermore the control law is given by:

$$\begin{aligned} u &= -(\mathbf{G}\tilde{\mathbf{B}})^{-1}(\mathbf{G}(\mathbf{f}(\mathbf{x}) + \Delta\mathbf{B}(\mathbf{x})u + \mathbf{d}(\mathbf{x}) - \dot{\mathbf{x}}_r) + \mathbf{D}\sigma) \\ &= -\frac{M}{k_v}(\mathbf{G}(\mathbf{f}(\mathbf{x}) + \Delta\mathbf{B}(\mathbf{x})u + \mathbf{d}(\mathbf{x}) - \dot{\mathbf{x}}_r) + \mathbf{D}\sigma) \end{aligned}$$

This means, the used value of the estimated moment of inertia directly influences the output torque. To make the controller a little more aggressive, the used value was set to $80 \cdot 10^{-6}$ kg m^2.

Question: There are some limitations on control parameters for controllers' stability. Which one?
One limitation is already given by the definition of the wanted derivative of the Lyapunov function candidate, which is $\dot{V}(\mathbf{x}) = -\sigma^T\mathbf{D}\sigma$. As this function is a quadratic form, which is positive definite if and only if the matrix $\mathbf{D}$ is positive definite, the parameter $\mathbf{D}$ needs to be positive in order to create a stable system. The next condition comes out of the definition of the used sliding surface σ. The used Lyapunov function ensures, that $\sigma \to 0$ as $t \to \infty$. This means that the following equation is true:

$$\sigma = k_p \cdot e + k_v \cdot \dot{e} \quad \rightarrow \quad 0 = k_p \cdot e + k_v \cdot \dot{e} \quad \rightarrow \quad \dot{e} = -\frac{k_p}{k_v}e$$

This means, that once the closed loop system has reached the sliding mode, it behaves like a first order linear system. The condition for this first order system to be stable is, that both parameters, k_p and k_v, have the same sign. Otherwise, the system is unstable. These two conditions are only general conditions, to be able to have an asymptotically stable closed loop system. According to the actual used parameters, the system can still be unstable.