Dynamics and motion control

Workshop B Servo control, code simulation and robustness.

1 Servo Control

There are two reasons why we sometimes have to extend the feedback design with a a carefully designed servo controller. The first is when the command/reference signal varies over a large range and it is important that we do not saturate the control signal to the process. The other is when it is important not only to control the position but also the velocity and perhaps even the acceleration of the process. For example, a gluing or painting robot.

To fulfil the first specification of not saturating the control we have to designing a trajectory planner. To fulfil the second specification we have to design a model following feed forward control law.

1.1 Trajectory planner

The model following control concept shown in the figure 1 is a variant of the feed forward

control that we have used so far i.e.

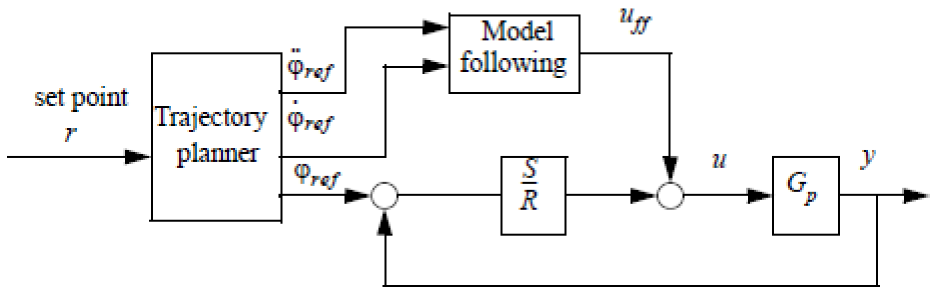
$$u = \frac{T}{R} r - \frac{S}{R} y$$

The main disadvantage with the control law, above is that it is difficult to design it such that the input does not saturate when the command varies within a larger range. Either you have to design the controller such that it saturates large reference inputs or such that it gives very slow response to small reference inputs.

One solution to the problem is to use a trajectory planner that generates the reference in a way that it does not saturate the control signal but still generates enough control so that the response is sufficiently fast. The trajectory has to be based on the knowledge of the process that you are controlling, maximum torque, speed etc.

1.2 Model following control

If the reference signal is designed so that it is as many times differentiable as the order of the process model then we can design a model following controller by inverting the process model in the time domain. A control structure for the DC-motor is depicted in the figure below where both the reference velocity and reference acceleration is necessary to invert the second order DC motor model.



Level 1

Design and implement in Simulink the model following control position for the DC-motor. It should consist of.

- A PID controller
- Trajectories for two different set points
  - Rs = 10 [rad]
  - Rs = 100 [rad]
- A model following controller that inverts the motor model.

2 Writing controller code

Now you should implement the controller from level 1 on a microprocessor. You therefore need to write the code in C, compile and download it. As always with programming you make mistakes and it is usually very difficult to debug code on an embedded system. However, there is a way of simulating the code in Simulink to verify it before trying to compile it. The code that you will write in Simulink is not C, it is a subset of normal Matlab m-code called Embedded Matlab or Matlab function depending on which Matalb version you are using.. It is however quite similar to C and if you do not use the matrix operations of Matlab is it actually very similar.

In the Simulink library under User Defined Functions there is a block called Embedded Matlab function.or Matlab function depending on Matlab version When you double click the block an editor opens where you can write code.

A Matlab function is just a m-file that starts with the keyword function. The syntax is

function [out_1,out_2,....,out_n] = function_name(in1_,in_2...in_n);

If you only have one output argument may you omit the brackets

Variables inside a function are local, that is they are not visible in Matlab command window or in any other m-file. The opposite is also true, variables defined at the Matlab prompt, directly or from any other m-file are not visible inside the Matlab function. It is similar to a function in C when you declare a variable inside the function, e.g., **float y**. This type of declaration makes the variables not only local but they lose their value after the execution of the function since they are volatile. All the states in the control code must however be saved in some way, i.e., non-volatile so that they can be used by the function each time it is called,

i.e., at each sample instant. In C this is achieved by defining the storage class of the variable as **static,** e.g., **static float y;**.
In Embedded Matlab this is achieved by declaring the variables using the key word **persistent,** e.g. **persistent** y1 y2**.** The command **persistent** initializes the declared variables to the empty matrix. To give the variables an initial value you can perform the following code patch.

```
persistent X

if isempty(X)

            X = 0;
End
```

Level 1

Write the code for the position controller from section 1.2 above including the trajectory planner and model following parts. Compare the model following Simulink **simulation** results from section 1.2 with those of the simulation of the Embedded Matlab implementation. Include the Embedded Matlab code in the report and show that it gives the same output as when using normal Simulink blocks.

Tips:

- To set the sample time of the Matlab function, right click the block and select "Block parameters".
- Develop step by step, do not try to do everything at once.
- Debug your coded controller function by comparing its output with a known Simulink block output of what you want it to do.
- When you have the same signal output from the Embedded Matlab function and the Simulink block, then you can apply it instead of the Simulink block.

Please show that the result from the embedded Matlab implementation is equal to the implementation using ordinary Simulink blocks. If there is any (small) difference try to describe what the reason for the difference is.

Level 2

If you not already have your PID controller implementation in state space format you should do that now.

Run the model following controller on the real motor by building your controller to the dSPACE real-time hardware.

Compare the results from the real motor with those of the simulated motor from level 1 above.

3 Robustness to parameter uncertainty and sensor noise

The two functions, Sensitivity function and Complementary Sensitivity function are useful tools for getting help with the difficult design problem of where the closed loop poles should be located.

One way (not the only) to select the closed loop poles is to divide the closed loop polynomial into two polynomials $A_m(s)A_o(s)$.
The closed loop response with a 2DOF design structure where $A_o(s)$ is cancelled in the response from to is and where is the noise added to the sensor.

$$y = \frac{Bt_0}{A_m} r + \frac{BS}{A_m A_o} n$$

Where t_0 is calculated to get unit dc-gain for a step response.

Start by selecting $A_m(s)$ from specifications, e.g. how fast should the response be and select the order of $A_m(s)$ the same as the order of the process model. Compute and plot the Sensitivity and Complementary Sensitivity functions.

$$S_e(s) = \frac{A(s)R(s)}{A_m(s)A_o(s)}$$

$$T_e(s) = \frac{B(s)S(s)}{A_m(s)A_o(s)}$$

Then select a couple of faster poles for $A_o(s)$, e.g., 2-5 times faster than $A_m(s)$ and plot $T_e(s)$ and $S_e(s)$ for them and compare.

If we have process parameters that are not perfectly known, inertia, friction, etc. or that they even vary during operation, then it is important to use a controller that has as low as possible maximum gain in the Sensitivity function.
If the sensor quality is low or it runs in a noisy environment then it might be more important to have a complementary sensitivity function with a low gain over a wider frequency range, especially at higher frequencies.

Level 2

Design a velocity controller for the valve controlled hydraulic cylinder. You do not have to make a discrete time controller, simulate the nonlinear hydraulic model and the continuous time controller with 0.5 m/s reference velocity (step response) and zero external force.

Try different closed loop pole locations, to simplify it start with the same frequency in both $A_m(s)$ and $A_o(s)$. Start with for example 100 rad/s and increase it in steps. Observe the step response and the peak responses of $T_e(s)$ and $S_e(s)$, the overshoot in the step response should decrease with increasing frequency. When you find a closed loop frequency where the improvements are small, select this for $A_m(s)$. Then select the frequency in $A_o(s)$ as a factor of $A_m(s)$, start with 1.0 and increase it until you are satisfied.

Deliver the following results in the report.

1.) Closed loop step response from Simulink using the nonlinear hydraulic cylinder model and the designed controller. Plot the response for for two different selections of $A_o(s)$ (same

$A_m(s)$) where you also apply a step in external force of 5000 N at a point in time when the velocity has stabilized at constant speed.

2.) for the same two $A_o(s)$ as in 1 change the mass in the nonlinear model to 200 kg instead of the 100 kg that you used when you designed the controller. That is, *you should not redesign the controller for the new weight, only change the weight it in the simulation model.*

3.) again for the same two $A_o(s)$ simulate with sensor noise, simulate the noise as a sine wave with amplitude 0,01 m/s and with a frequency that you select yourself so that you can see the difference in the step responses for the two $A_o(s)$ (using the same frequency). Use $T_e(s)$ and compare the time plots with the gain $T_e(s)$ in for the noise frequency.

Give a brief discussion of your results in the report.

If you want to can you design a position controller for the cylinder by extending the velocity loop with a other position loop. This should be very simple since the design model you have to use for the position loop is simply

$$y(s) = \frac{1}{s} v(s)$$

where *y* is the position and *v* the velocity.