

# 1 Exercise 1

## 1.1

This is the tap that connects the upper tank to the water reservoir. If the gain is set to 0, this means that there is no contribution from this when the upper tank is being emptied, i.e. the tap is closed.

## 1.2

The transfer functions was implemented in the presented code.

## 1.3

**The step block**, the initial value for the step block is set to 0 meaning that the step will start with this value. The step time is set to 100 meaning that the step will come at  $t = 100$  and the final value is set to 10 meaning that the step will step from 0 to 10.

**The constant block**, this will give a constant output of 40.

**The summation block**, this will add together both the step- and constant block and the output will be the sum of these to. The reference block will therefore at time 100 have a step from 40 to 50

## 1.4

The function and the transfer function was added to the script.

## 1.5

$\zeta$	$\chi$	$\omega_0$	$T_r$	$M$	$T_{settling}$
0.5	0.7	0.1	8.4	14.0	45,4
0.5	0.7	0.2	4.9	26.9	37.0
0.5	0.8	0.2	5.0	31.7	26.5

The last control parameters will give values that is within the requirements. Therefore will this be the best controller for us.

## 1.6

The crossover frequency for the open loop system,  $F(s)G(s)$  can be found by solving for  $0dB$  when  $s = j\omega$

$$|F(j\omega)G(j\omega)| = 1 \quad (1)$$

This will give the crossover frequency  $\omega_c = 0.362 \text{ rad/s}$ .

## 1.7

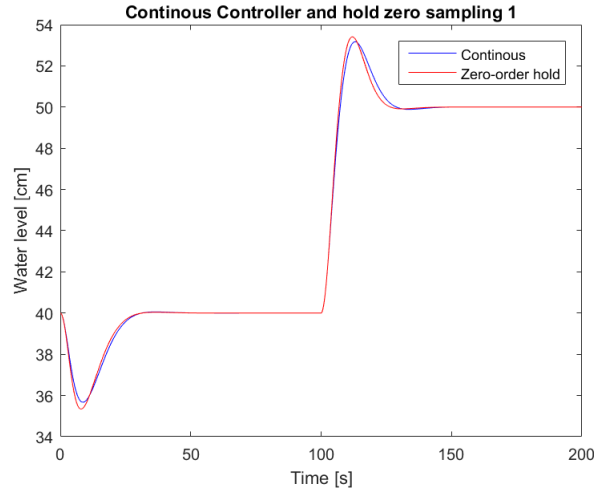


Figure 1: Step response from the continuous controller and the ZOH

As seen in figure 1.7, the system with the zero order hold is a bit quicker although there is more overshoot.

## 1.8

When comparing the ZOH to the discrete controller with step size 1, will the ZOH give a quicker system with more overshoot. The discrete controller will have significantly longer settling time.

When the sample size is increased to 2, there will be even larger differences, the overshoot from the zero order hold will increase some and the settling time for the discrete controller is much worse.

## 1.9

If we allow a phase deterioration of  $20^\circ$  we can calculate the sampling frequency as

$$\omega_s \approx \frac{2\pi\omega_{cutoff}}{0.35}, \quad (2)$$

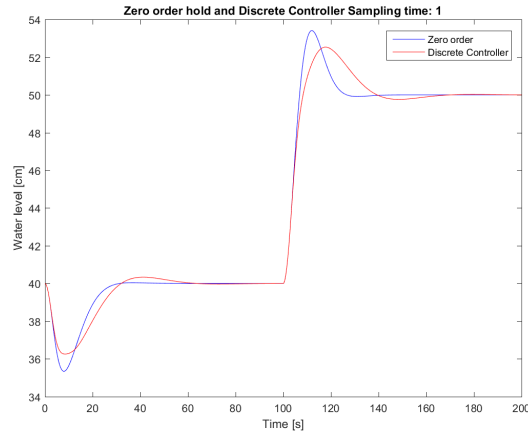


Figure 2: Step response for ZOH compared to discrete controller with sample time 1

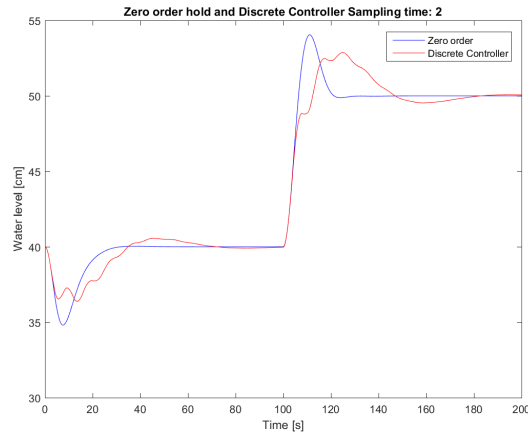


Figure 3: Step response for ZOH compared to discrete controller with sample time 2

which gives us the sampling time as,

$$T = \frac{2\pi}{\omega_s} = 0.1539 \quad (3)$$

**1.10**

**1.11**

Insert picture

### 1.12

The coefficients for the discrete systems were derived by using the `c2d` command in MATLAB which transforms a continuous time system to a discrete time system. The coefficients are the following:

$a_1$	$a_2$	$b_1$	$b_2$
0.0916	0.0739	-1.4497	0.5254

### 1.13

The poles needs to be inside the unit circle for the system to be stable.

### 1.14

The pole polynomial is

$$z^4 + d_0z^3 + d_1z^2 + d_2z + d_3 \quad (4)$$

with the following values

$d_0$	$d_1$	$d_2$	$d_3$
-1.2061	0.5495	-0.0924	0.0051

### 1.15

We have the following closed loop system

$$Gc(s) = \frac{F_d G_d}{1 + F_d G_d} \quad (5)$$

which can be rewritten to

$$Gc(s) = \frac{F_{num} * G_{num}}{F_{den} * G_{den} + F_{num} * G_{num}} \quad (6)$$

The equation for the poles in the closed loop system is therefore

$$F_{den} * G_{den} + F_{num} * G_{num} = 0 \quad (7)$$

Replacing the terms in the equation with its corresponding polynomial and setting this equal to the pole polynomial of the discrete-time closed loop system we get

$$(z-1)(z+r)(z^2+b_1z+b_2)+(c_0z^2+c_1z+c_2)(a_1z+a_2) = z^4+d_0z^3+d_1z^2+d_2z+d_3 \quad (8)$$

By expanding the left side of the equation following polynomial is derived

$$z^4 + z^3(a_1c_0 + b_1 + r - 1) + z^2(a_1c_1 + a_2c_0 + b_1r + b_2 - b_1 - r) + z(a_1 + c_2 + a_2c_1 + b_2r - b_1r - b_2) + a_2c_2 - b_2r \quad (9)$$

This gives the corresponding expression for the right side's  $d_i$  values

$d_0$	$d_1$	$d_2$	$d_3$
$a_1c_0 + b_1 + r - 1$	$a_1c_1 + a_2c_0 + b_1r + b_2 - b_1 - r$	$a_1 + c_2 + a_2c_1 + b_2r - b_1r - b_2$	$a_2c_2 - b_2r$

Which can be represented in matrix form.

$$\begin{bmatrix} 1 & a_1 & 0 & 0 \\ b_1 - 1 & a_2 & a_1 & 0 \\ b_2 - b_1 & 0 & a_2 & a_1 \\ -b_2 & 0 & 0 & a_2 \end{bmatrix} \begin{bmatrix} r \\ c_0 \\ c_1 \\ c_2 \end{bmatrix} = \begin{bmatrix} d_0 - b_1 + 1 \\ d_1 - b_2 + b_1 \\ d_2 + b_2 \\ d_3 \end{bmatrix} \quad (10)$$

## 1.16

By using the solver command in Matlab the values for  $r, c_0, c_1$  and  $c_2$  could be calculated.

r	$c_0$	$c_1$	$c_2$
0.4543	8.6154	-10.3654	3.2973

The poles of the closed loop system are

$p_1$	$p_2$	$p_3$	$p_4$
0.1353	0.1353	0.4677+0.2453i	0.46677-0.2435i

which is the same as in Question 11.

## 1.17

Insert compare picture.

## 1.18

An input difference of 0-100 with a 10-bit A/D converter gives a quantization level of

$$\frac{100}{2^{10}} = 0.0977 \quad (11)$$

## **1.19**

Yeah, we tried that...

## **1.20**

When a quantization level of NUMBER was used the control performance started to be degraded. This corresponds to a 6 bit A/D converter.

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