Three-Tank-System operator manual

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Control Systems

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Contents

Chapter 1

Introduction

This document is the operator manual for the Three-Tank-System lab setup shown in Figure 1.1, designed by Gurski [1]. The Three-Tank-System is connected to a dSpace DS1104 single board system. In between these systems an interface board is placed to connect wires easily. Important steps for an operational lab setup connected to a dSpace system are presented in this report. Furthermore, this report provides technical specifications about the Three-Tank-System, its actuators, sensors and amplifiers. Also, the connection between dSpace and the Three-Tank-System is described, including the implementation in Matlab Simulink. Finally a ControlDesk layout is presented in which signals can be read and edited in real time.

Table 1.1: Three-Tank-System components

ID	Component	ID	Component
1	Pump 1	4	Pressure sensor 1, 3 and 2 (from left to right)
2	Pump 2	5	Tank 1, 3, and 2 (from left to right).
3	Valve 4, 1, 5, 2, 6, 3 (from left to right)	6	Reservoir

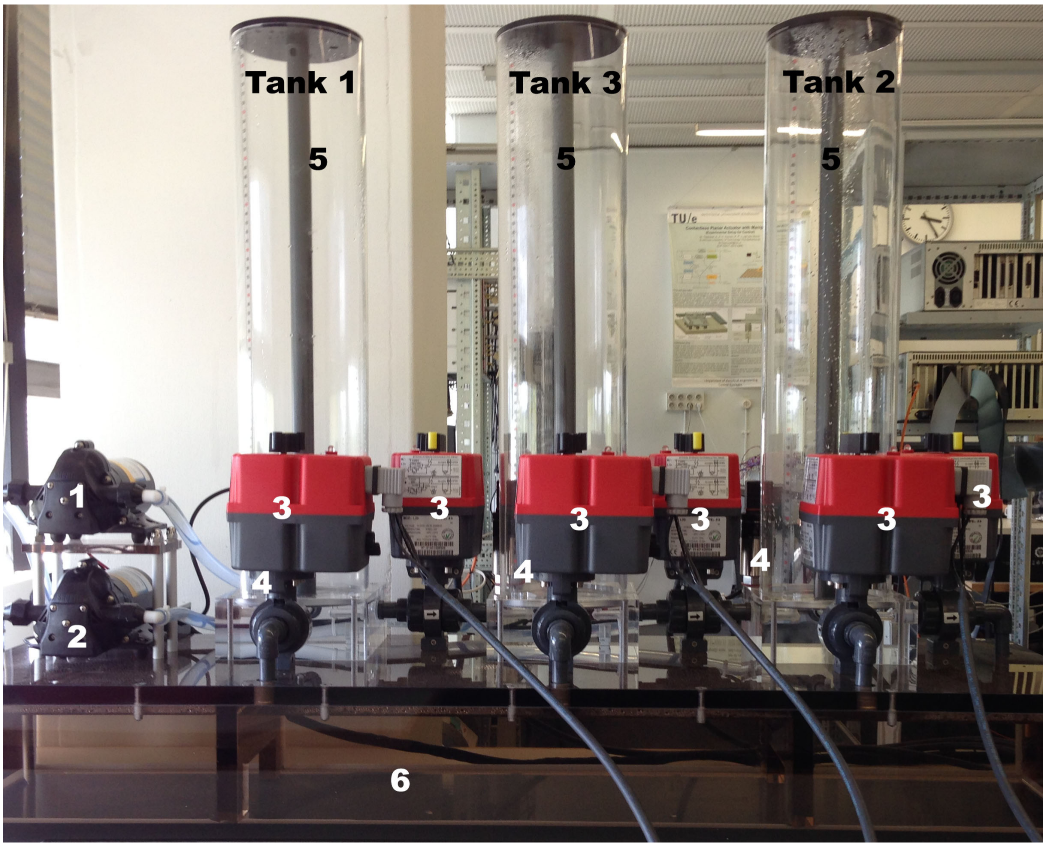


Figure 1.1: Three-Tank-System overview

1.1 System overview

Figure 1.1 and Table 1.1 show the Three-Tank-System with numbered components. Figure 1.2 illustrates a functional overview of the Three-Tank-System. The system consists of three tanks, which can be filled with a substance. Tank 1 and tank 2 can be filled by pump 1 and 2, denoted by Q_1 and Q_2 (flow 1 and 2), respectively. Tank 1 and tank 3 and tank 3 and tank 2 are connected with adjustable valves. The flow from the tanks is denoted by Q_{13} and Q_{32} respectively. Tank 3 has an output flow, denoted by Q_{20}. Furthermore, leaks can be simulated for each tank with adjustable valves, these are denoted as Q_{l1}, Q_{l2} and Q_{l3} for tank 1 trough 3 respectively. The flows Q_1 and Q_2 can be controlled with the pumps, the other flows can be controlled with valves. The height of the water level for each tank can be measured with pressure sensors. When a tank reaches its maximum height level (approximately 620 [mm]), the corresponding pump will automatically shut down, until the water is below maximum level, in order to prevent overflow of water. This will provide technical specifications on the sensors, pumps and valves. Information about the Three-Tank-System can also be found in [1].

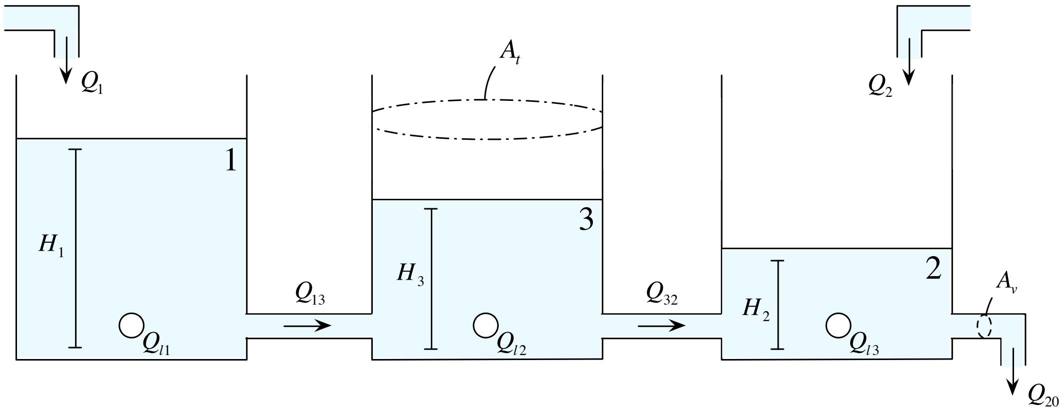


FIGURE 1.2: Three-Tank-System functional scheme

Chapter 2

Three-Tank-System technical specifications

This Chapter will provide technical data about the two pumps, the valves, the pressure sensors, the amplifier and the adapter box.

2.1 Cylinder tanks and reservoir

The Three-Tank-System consists of a main reservoir, holding approximately 40 [L] of water, and three cylinder tanks on top of the reservoir, each of these tanks can hold approximately 9 [L] of water. The pumps pump water out of the reservoir in to tanks 1 and 2. The water flowing out of the tank, through the valves, comes back in the reservoir. Tables 2.1 and 2.2 show the dimensions of the reservoir and tanks respectively.

Table 2.1: Reservoir

Dimensions	Value	Unit
Length	1200	[mm]
Depth	350	[mm]
Height	160	[mm]
Capacity ca.	43	[l]

Table 2.2: Cylinder Tank

Dimensions	Value	Unit
Diameter outside	150	[mm]
Diameter inside	140	[mm]
Diameter inner flow pipe	25	[mm]
Height max. liquid level	630	[mm]
Capacity ca.	9	[l]

2.2 Pressure Sensors

To measure the height of the water in a tank, pressure sensors are used. These pressure sensors behave approximately linear, with a level range of 0 to 700 [mm] and an output range of +10 to -10 [V]. Characteristics of the sensors are measured by putting water in a tank at a certain height, measured with a ruler, followed by measuring the sensor output voltage. These results are shown in Table 2.3.

Table 2.3: Pressure sensor measurement data

Height [mm]	Tank 1 Vout [V]	Tank 2 Vout [V]	Tank 3 Vout [V]
0	10	10	10
50	8.800	8.780	8.630
100	7.310	7.250	7.150
150	5.830	5.780	5.700
200	4.340	4.280	4.186
250	2.800	2.820	2.672
300	1.390	1.330	1.234
350	-0.090	-0.170	-0.267
400	-1.580	-1.650	-1.764
450	-3.060	-3.080	-3.228
500	-4.540	-4.590	-4.727
550	-6.020	-6.090	-6.165
600	-7.500	-7.580	-7.680

The results in the table are approximately linear, especially for heights above 100 [mm]. For heights below 100 [mm], the line is curving a little bit downwards, therefore a fourth order polynomial fit is chosen to comply for this behavior. The results can be written as a polynomial of the form $p(x) = p_1x^4 + p_2x^3 + p_3x^2 + p_4x + p_5$, where $p(x)$ is the height in [mm] and x is the voltage in [V]. The values are shown in Table 2.4.

Table 2.4: Pressure sensors least squares data

	Tank 1	Tank 2	Tank 3
p_1	-0.001666	-0.00179	-0.0001865
p_2	-0.0009633	0.002802	-0.0009999
p_3	0.09951	0.1066	0.0174
p_4	-33.68	-33.81	-33.62
p_5	346.2	344.1	341.0

2.3 Pumps

Two pumps are used to pump water into tank 1 and 2. The input voltage for the pumps is 0 to 10 [V], where 0 [V] gives an output flow of 0 [L/min] and 10 [V] gives the maximum output flow. Note that the pumps can handle 0 to 12 [V] with an output flow of approximately 7.5 [L/min], but the amplifier output is limited at 10 [V]. Characteristics of the pumps are measured by applying a constant voltage for a certain amount of time. The height of water that is pumped into the tanks (with all valves closed) is measured afterwards with a ruler that is mounted on the tank. Since the dimensions of the system are known, the output flow can be calculated. The measurement results are shown in Table 2.5.

Table 2.5: Pumps measurement data

Vin [V]	Pump 1 out [L/min]	Pump 2 out [L/min]
10	6.03	6.54
9	5.37	5.85
8	4.92	5.14
7	4.33	4.64
6	3.72	4.14
5	3.14	3.34
4	2.43	2.69
3	1.82	2.01
2	1.21	1.31
1	0.57	0.50
0	0	0

Linear least squares regression is applied to determine the linear behavior of the pumps. The results can be written in the form of $q(x) = vx$, with $q(x)$ being the flow rate in [L/min] and x the input voltage [V]. The values are shown in Table 2.6.

Table 2.6: Pumps least squares data

	Pump 1	Pump 2
x	0.6092	0.6581

Maximum values of the pump are shown in the Table below (Table 2.7).

Table 2.7: Pumps

Max. Flow	Value	Unit
Pump 1	6.03	[L/min]
Pump 2	6.54	[L/min]

2.4 Valves

Electrical control valves are used to change the system dynamics. These valves are controlled with an TTL signal, this means on or off, as shown in Table 2.8. These valves have end switches which indicate if the valve is fully open or fully closed (Table 2.9), and also a potentiometer to measure the current position the valve is in. The voltage over the potentiometer can be measured and the limits are shown in Table 2.10. The relation between the opening of the valve (surface area) and the output flow is not given by the manufacturer of the system. No measurements have been done to determine this behaviour.

Table 2.8: Input signal logic Table

Open valve	Close valve	State
0	0	Valve switched off
0	1	Valve closes
1	0	Valve opens
1	1	Invalid

Table 2.9: Limit switch logic Table

Open	Closed	State
0	0	Valve in between states
0	1	Valve fully closed
1	0	Valve fully opened
1	1	Invalid

TABLE 2.10: Valves measurement data

Valve #	Fully open [V]	Fully closed [V]
1	-1.63	3.11
2	-2.21	2.47
3	-2.54	2.20
4	-2.58	2.33
5	-2.28	2.46

Valve sections are found in the Table below (Table 2.11).

TABLE 2.11: Valves

Effective flow area	Value	Unit
Connection pipes	$5 * 10^{-5}$	$[m^2]$
Leakage openings	$5 * 10^{-5}$	$[m^2]$

2.5 Amplifier

The pumps and sensors are connected to the amplifier. This amplifier provides access to several settings for the pumps and sensors. The rear panel (Figure 2.2) has a connector that is to be connected to the pumps and sensors. There is a connector that is to be connected to the dSPACE system located as well. The front panel displayed in Figure 2.1 gives access to the settings and indicators for the Three-Tank-System. Each of these sections of the front panel are discussed below.

FIGURE 2.1: Front panel of the amplifier

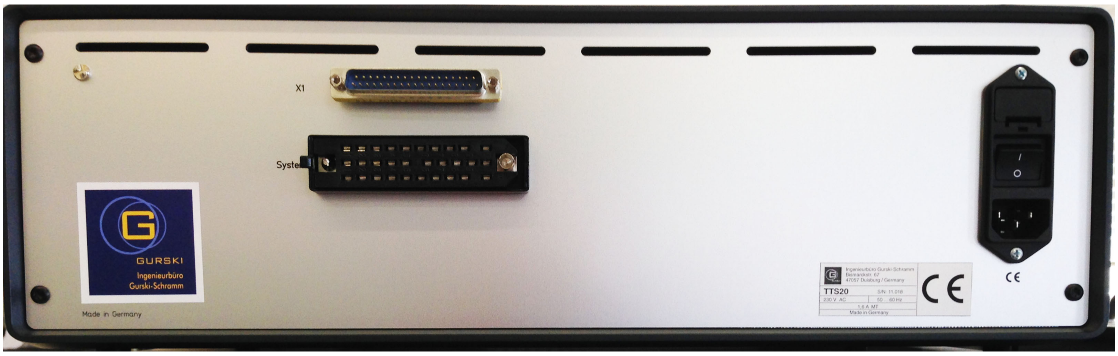


FIGURE 2.2: Rear panel of the amplifier

2.5.1 Servo Pump 1 and 2

There are two sections for the pumps located on the left-hand side of the front panel. Servo Pump 1 controls the flow of pump1, connected to the left tank (tank 1), and Servo Pump 2 controls the flow for pump 2, connected to the right tank (tank 2). There are two LEDs, a switch and a potentiometer that indicate the state of operation.

- Ready : The voltage supply is active.
- Limit : The maximum liquid level of the corresponding tank is reached (pump 1 for the left tank and pump 2 for the right tank) and the pump is switched off.
- Switch Automatic or Manual : This switch allows to change from automatic control (via dSPACE or another system) and manual control of the pumps.
- Potentiometer : Provides manual control for the pumps, the flow can be adjusted using this potentiometer.

2.5.2 System status

This LED indicates whether the pump amplifiers are enabled. This should always be true since the protection is bypassed. (The pumps have to receive a certain signal in order to go in operational mode for protection. This protection is bypassed and thus the pumps can be directly controlled.)

2.5.3 Power

This panel contains three LED indicators for the power supply.

2.5.4 Monitor

The monitor panel provides access for reading (for example using a digital multi meter (DMM)) of the sensor signals and pump control signals.

2.5.5 Signal error

A schematic overview of this section is depicted in Figure 2.3.This section allows for scaling of the processed sensor and control signals in a range of 0% to 100%. By means of the three switches (off - scaled switch in the schematic overview), a total sensor failure for each of the sensors can be simulated. The potentiometers (scaling block in the schematic overview) scale the signal of the sensors signals or control signals in a range of 0% to 100%.

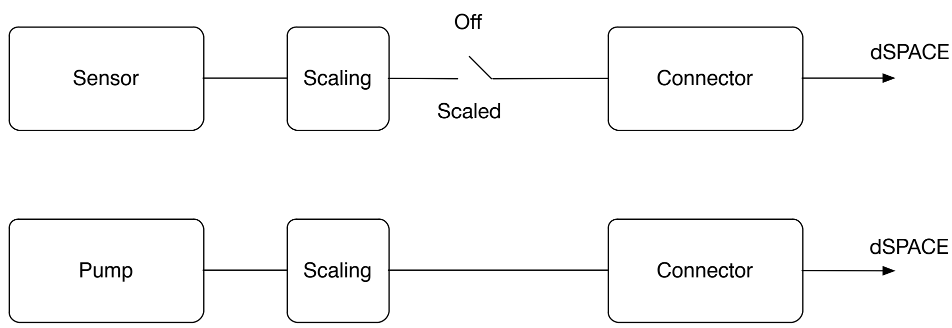


Figure 2.3: Schematic overview of the sensor and pump scaling

2.6 Valve adapter box

The adapter box serves as an interface between the electrical control valves and the dSPACE system. On the rear panel (Figure 2.5) two connectors are located. These connectors are to be connected to the dSPACE system. The front panel (Figure 2.4) sections of the adapter box contain switches and indicators for the valves. On the left three LED indicators for the DC power supplies are located. These LEDs indicate the availability of the DC voltages. The rest of the adapter box is filled with six panel sections for the valves. These panels each have LED indicators that indicate the availability of the power supply, if the valve is completely open or if the valve is completely closed. Switches are used to open or close a valve. If this switch is in its middle position the valve can be controlled by an external signal.

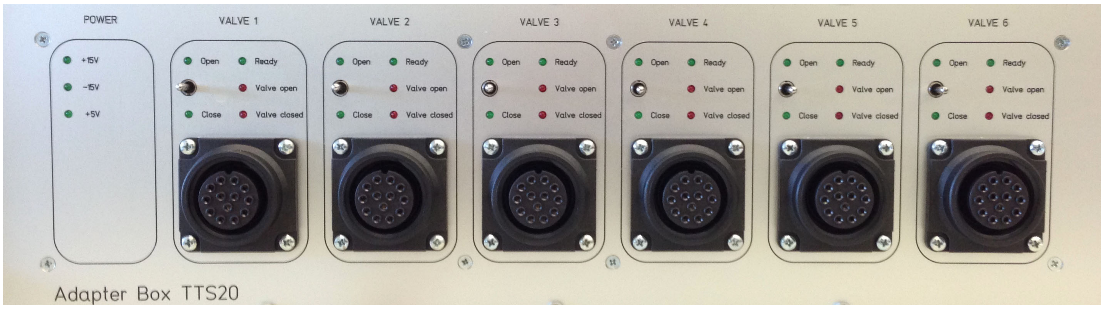


FIGURE 2.4: Front panel of the adapter box

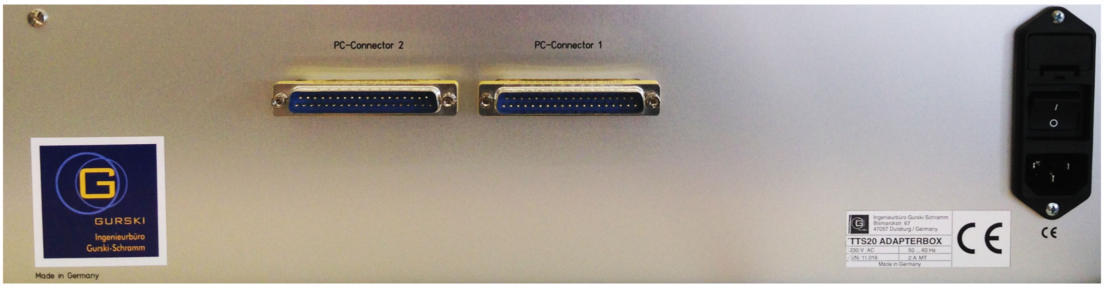


FIGURE 2.5: Rear panel of the adapter box

Chapter 3

Controlling the TTS from Simulink

This Chapter explains how the Three-Tank-System is connected to the dSpace system. An overview of the complete system is illustrated in Figure 3.1. The steps illustrated in this Figure are explained in this Chapter. The first step is to map all the components to the dSpace system. Secondly, an interface in Simulink is made where signal routing and conversions take place. Finally, a layout in ControlDesk is given. This layout makes it possible to observe and edit parameters, in real time, running on the dSpace system.

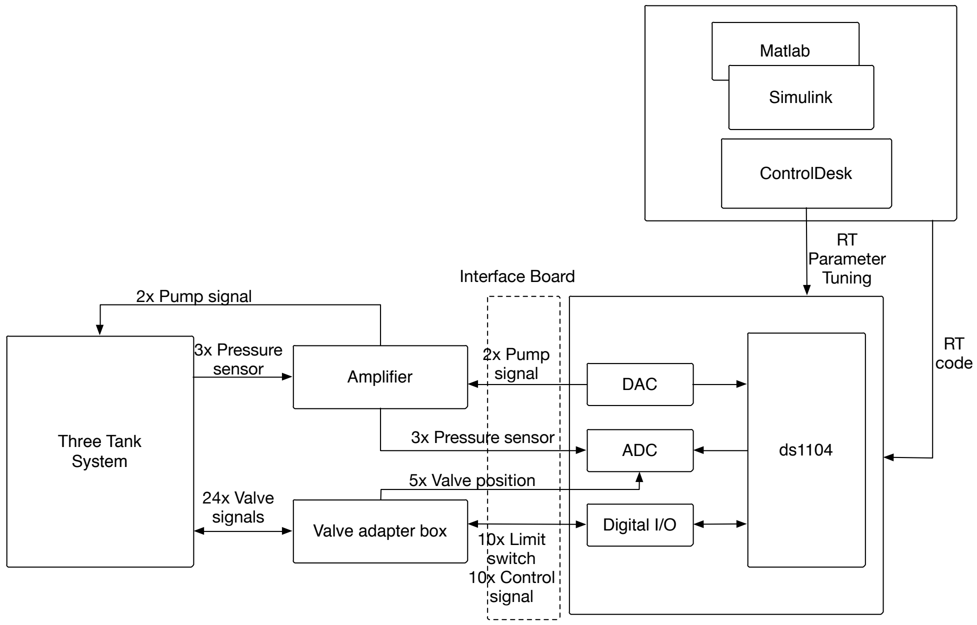


FIGURE 3.1: Block diagram showing the overview of the Three-Tank-System and dSpace system.

3.1 Connecting of the Three-Tank-System to dSpace

The goal is to design, implement and test controllers for the Three-Tank-System. To do this a dSpace (DS1104) system is used. This system comprises, inter alia, digital to analog converters (DAC), an analog to digital converters (ADC) and digital input and output (I/O) ports. From Chapter 2 it is known that the amplifier (Section 2.5) has one I/O connector which goes to the dSpace system and the adapter box (Section 2.6) has two I/O connectors.

A breakout board has been designed on which the three connectors described above can be plugged in. These signals are then distributed to several outputs which have to be connected to the dSpace DS1104 system. These connectors are all labeled and should be easy to plug in. The pin layout and overview can be found in appendix A. A picture of the breakout-board is shown in Figure 3.2. An overview of each digital I/O connection of the TTS set-up to the dSPACE DS1104 system is shown in Table 3.1.

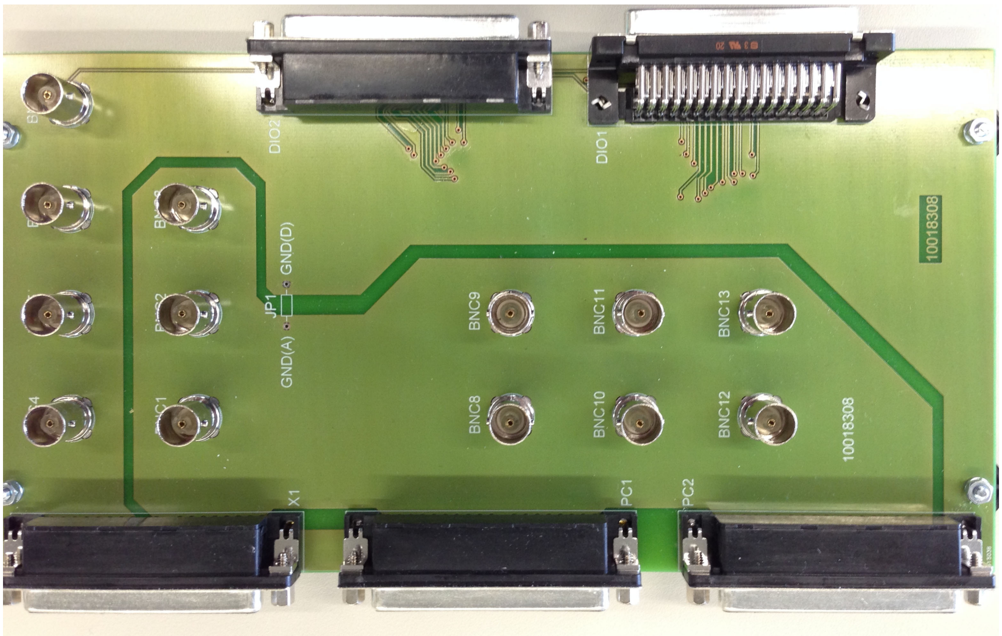


FIGURE 3.2: Breakout board, connecting the dSPACE system and the TTS.

TABLE 3.1: I/O Table

Valve # and operation	I/O port	Valve # and operation	I/O port
V1 Switch 'opened'	IO10	V1 Switch 'closed'	IO11
V2 Switch 'opened'	IO12	V2 Switch 'closed'	IO13
V3 Switch 'opened'	IO14	V3 Switch 'closed'	IO15
V4 Switch 'opened'	IO16	V4 Switch 'closed'	IO17
V5 Switch 'opened'	IO18	V5 Switch 'closed'	IO19
V1 Open	IO0	V1 Close	IO1
V2 Open	IO2	V2 Close	IO3
V3 Open	IO4	V3 Close	IO5
V4 Open	IO6	V4 Close	IO7
V5 Open	IO8	V5 Close	IO9

3.2 Controlling the Three-Tank-System from Simulink

To actuate the motors and read out the sensors, dSPACE real time code will be generated from Simulink models. This is done with Simulink's code builder, with compatibility for dSPACE. dSPACE I/O hardware is represented in Simulink by a dedicated dSPACE block library. The Sections below will describe the blocks needed to interface with the TTS set-up.

3.2.1 Pressure Sensors

The height of water in one of the tanks can be determined by reading out the voltage that the pressure sensor is sending. This is done by an ADC, with a resolution of 16 bits, within the ds1104 module. The ADC has an input range of +/- 10 [V]. Within simulink this signal is normalized to a +/- 1 signal (a signal of +10 [V] from the sensor produces a signal of +1 in Simulink). Figure 3.3 illustrates the block, to be used in Simulink, that reads out the ADC channels. Within this block the normalization is countered to get the full range back from the sensor. Then the height level of the tanks is calculated as presented in Section 2.2 and again shown in Equation 3.1 and Table 3.2. The contents of this block are shown in Figure 3.4.

$$p\left(x\right) = p_1 x^4 + p_2 x^3 + p_3 x^2 + p_4 x + p_5. \tag{3.1}$$

TABLE 3.2: Pressure sensors least squares data

	Tank 1	Tank 2	Tank 3
p_1	-0.001666	-0.00179	-0.0001865
p_2	-0.0009633	0.002802	-0.0009999
p_3	0.09951	0.1066	0.0174
p_4	-33.68	-33.81	-33.62
p_5	346.2	344.1	341.0

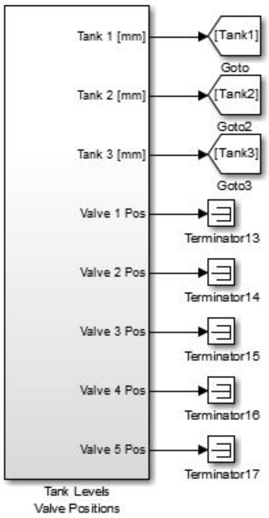


FIGURE 3.3: Matlab Simulink block to read the pressure sensors and valve potentiometers.

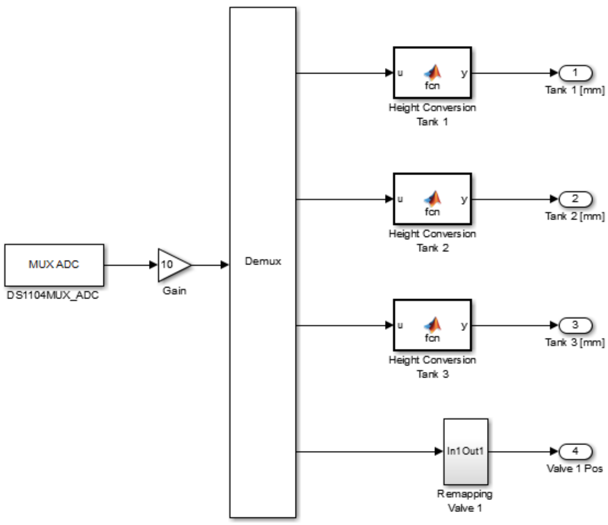


FIGURE 3.4: Content of the block shown in Figure 3.3. Three channels privide reading and conversion for the pressure sensors. The other channel provides reading and conversion for the valves.

3.2.2 Pumps

To get water in the tanks, pumps 1 and 2 have to be actuated. These pumps have an input range of 0 - 10 [V]. The amplifier has an input for the pumps in the range of -10 - +10 [V], which is then converted to the input range of the pumps. The control signal coming from dSPACE is converted by an DAC with a resolution of 16 bits and a range of +/- 10 [V]. Within Simulink this signal is normalized to +/- 1. The block that is used within Simulink is shown in Figure 3.5. The contents of this block are shown in Figure 3.6. This block converts the corresponding flow rate to a voltage signal as presented in Section 2.3 and again shown in equation Equation 3.2 and Table 3.3.

$$q\left(x\right) = vx. \tag{3.2}$$

Table 3.3: Pumps least squares data

	Pump 1	Pump 2
x	0.6092	0.6581

After this first conversion, the signal is mapped from a 0-10 [V] input range to a -10 - +10 [V] input, and thereafter normalized to -1 - +1 range to match the dSPACE ADC output.

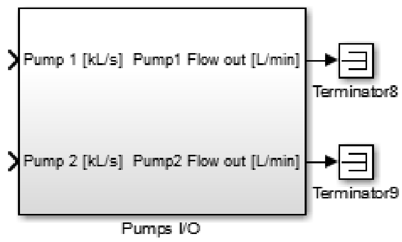


Figure 3.5: Matlab Simulink block to send signals to the pumps.

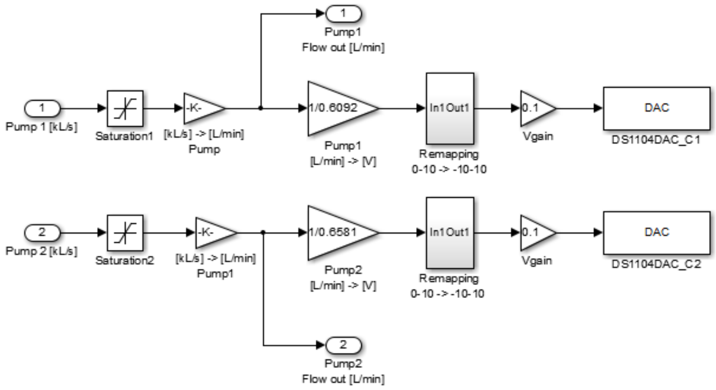


FIGURE 3.6: Content of the block shown in Figure 3.5

3.2.3 Valves

To control the positions of the valves, the block displayed in Figure 3.7 is used. The valves are controlled by digital outputs as presented in Section 2.4. Figure 3.8 and Figure 3.9 show the content of the valve block.

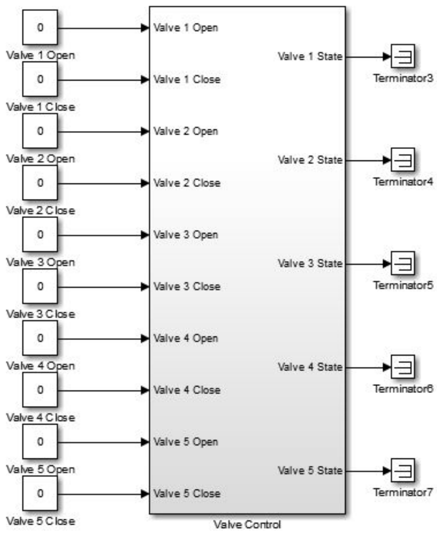


FIGURE 3.7: Matlab Simulink block to send signals to the valves and to receive their fully open or closed states.

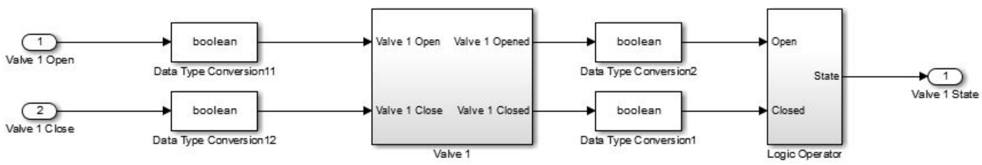


FIGURE 3.8: Content of the block shown in Figure 3.7. This content only applies for one of the valves and is repeated for every valve.

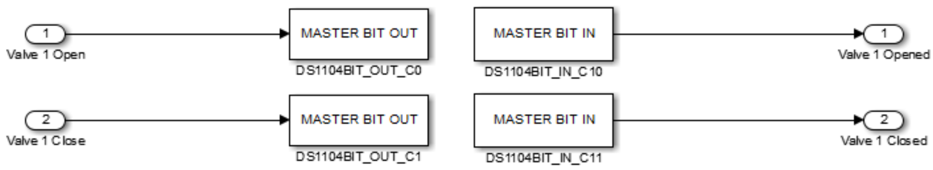


FIGURE 3.9: Content of the block shown in Figure 3.8. This content only applies for one of the valves and is repeated for every valve. It shows the digital I/O connection with dSPACE in Simulink.

A high or low signal can be sent to the valves to open or close them. The valve also includes limit switches. These switches give a true or false signal when the valve has reached a fully open or closed state, this is also shown in Table 2.9. The output of these two signals are then converted by a logic operator that gives outputs according to Table 3.4. These output states are currently not used in the dSPACE environment.

TABLE 3.4: Limit switch logic table

Open	Closed	State	Output
0	0	Valve in between states	2
0	1	Valve fully closed	0
1	0	Valve fully opened	1
1	1	Invalid	10

Furthermore, the valves have a built in potentiometer. The current position that the valve is in can be determined with this potentiometer. The output of these potentiometers are in the same block as the pressure sensor is (Figure 3.3 and Figure 3.4). Because of possibilities within the software, the pump and valve data could not be separated into a separate block. The ADC provides a signal with a resolution of 12 bits. This signal is normalized from a range of [-10, +10] [V] to a range of [0, 1]. the output of the valve position block is normalized in a range of [0, 1], where 0 means fully closed and 1 is fully open. To achive this result, the normalization of the ADC is first countered and then the range of the potentiometers displayed in Table 2.10, is normalized to the range of [0, 1].

3.3 dSPACE ControlDesk interface

In order to read and edit real-time valvues, dSPACE ControlDesk 3.7.5 is used. This program allows the user to read and edit parameters from the Simulink model in real-time. The layout that has been made for ControlDesk in show in Figure 3.10. The red outlining shows the panel where the levels of the water tanks can be read out. These values are graphically displayed in the form of a tank, as well as a numeric display. The green box outlines the valve control panel. From this panel, valves can be opened or closed by holding down the corresponding button. The current position of the valves can be read out from the display. The cyan outlined box shows the flow rate of the pumps. Finally, a plot window is displayed in the blue outlining, which contains plots of the pump inputs as well as the tank levels.

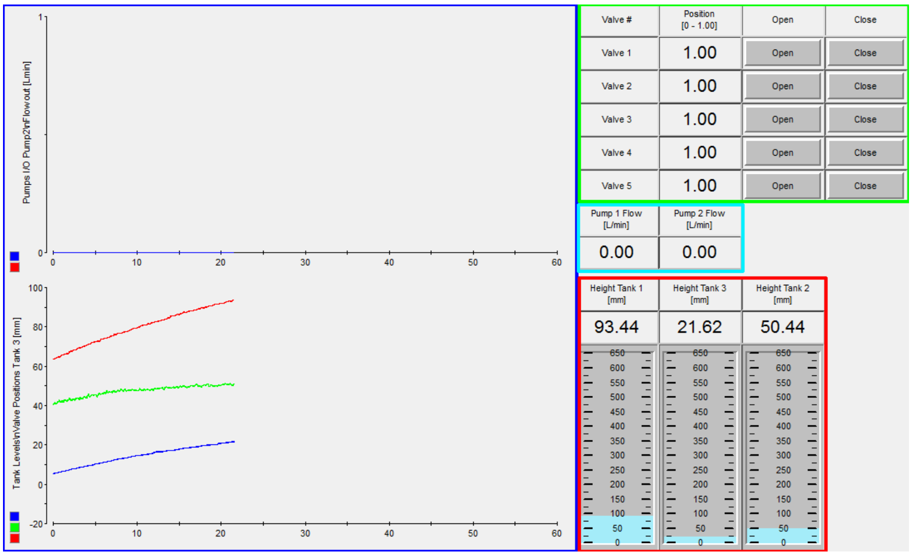


FIGURE 3.10: Three-Tank-System layout for dSPACE ControlDesk 3.7.5.

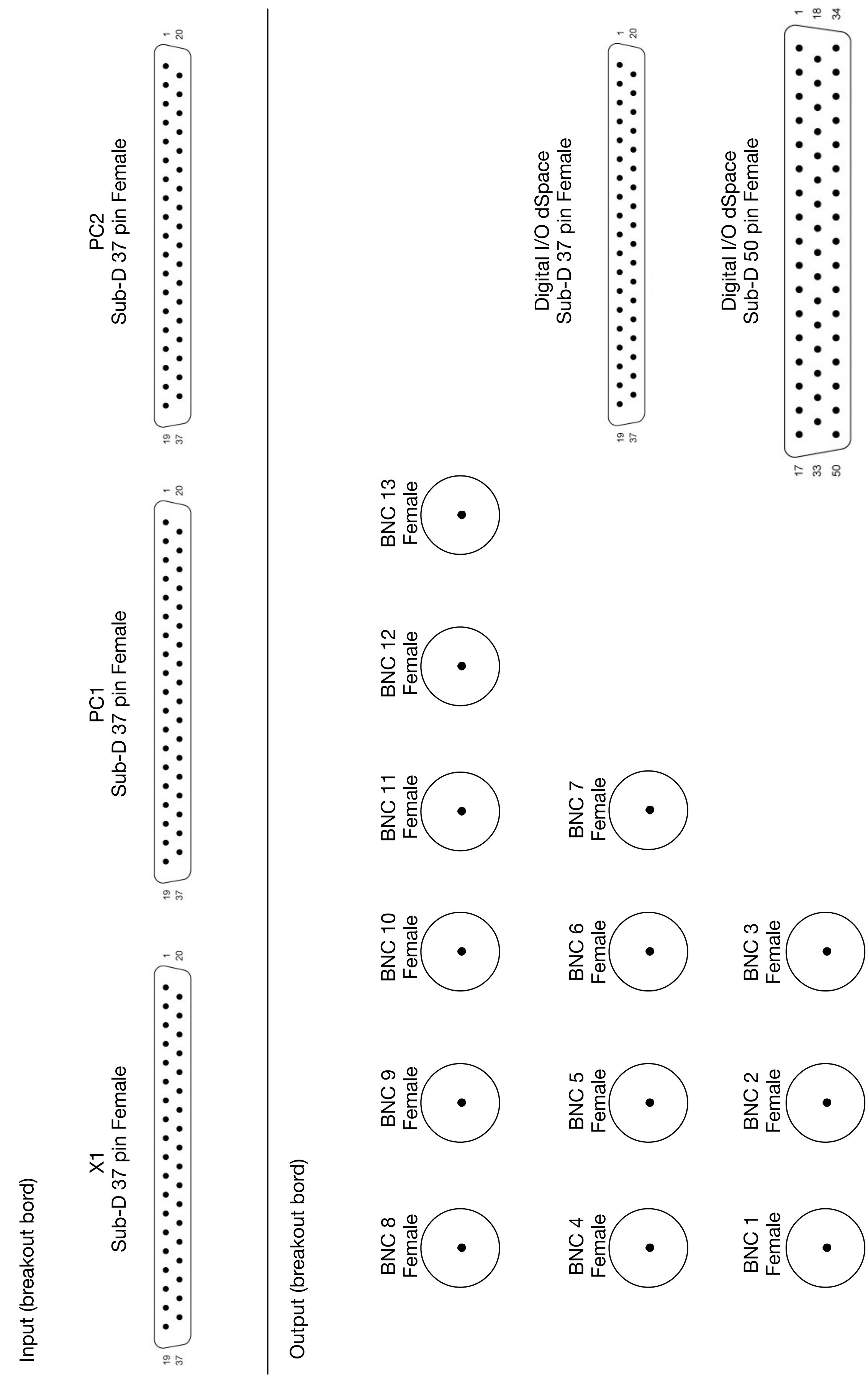
Appendix A

Pin mapping

Input	Description	Output 1	Output 2
Sub-D37 X1 Female		BNC	
Pin 1	Level tank1 (A)	BNC1 +	
Pin 2	Level tank2 (A)	BNC2 +	
Pin 3	Level tank3 (A)	BNC3 +	
Pin 9	GND (A)	BNC1,2,3 -	
		BNC	Sub-D50
Pin 20	Pump 1 (D)	BNC4 +	
Pin 21	Pump 2 (D)	BNC5 +	
Pin 29	GND (D)	BNC4,5,6,7 -	Pin 17
Pin 31	Pulse (D)	BNC6 +	Pin 13
Pin 32	Rect (D)	BNC7 +	Pin 30

Input	Description	Output 1	Output 2
Sub-D37 PC1 Female		BNC	
Pin 1	Valve1 pos (A)	BNC8 +	
Pin 2	Valve2 pos (A)	BNC9 +	
Pin 3	Valve3 pos (A)	BNC10 +	
Pin 4	Valve4 pos (A)	BNC11 +	
Pin 9	GND (A) for pin 1,2,3,4	BNC8,9,10,11 -	
		Sub-D37	Sub-D50
Pin 12	V1 Switch 'opened' (D)	Pin 27	Pin 7
Pin 13	V1 Switch 'closed' (D)	Pin 9	Pin 24
Pin 14	V2 Switch 'opened' (D)	Pin 29	Pin 8
Pin 15	V2 Switch 'closed' (D)	Pin 11	Pin 25
Pin 16	V3 Switch 'opened' (D)	Pin 30	Pin 9
Pin 17	V3 Switch 'closed' (D)	Pin 12	Pin 26
Pin 18	V4 Switch 'opened' (D)	Pin 32	Pin 10
Pin 19	V4 Switch 'closed' (D)	Pin 14	Pin 27
Pin 29	GND (D) (All digital pins)	Pin 4	Pin 17
Pin 30	V1 Open (D)	Pin 20	Pin 1
Pin 31	V1 Close (D)	Pin 2	Pin 18
Pin 32	V2 Open (D)	Pin 21	Pin 2
Pin 33	V2 Close (D)	Pin 3	Pin 19
Pin 34	V3 Open (D)	Pin 23	Pin 3
Pin 35	V3 Close (D)	Pin 5	Pin 20
Pin 36	V4 Open (D)	Pin 24	Pin 4
Pin 37	V4 Close (D)	Pin 6	Pin 21

Input	Description	Output 1	Output 2
Sub-D37 PC2 Female		BNC	
Pin 1	Valve5 pos (A)	BNC12 +	
Pin 2	Valve6 pos (A)	BNC13 +	
Pin 9	GND (A) for pin 1,2	BNC12,13 -	
		Sub-D37	Sub-D50
Pin 12	V5 Switch 'opened' (D)	Pin 33	Pin 11
Pin 13	V5 Switch 'closed' (D)	Pin 15	Pin 28
Pin 14	V6 Switch 'opened' (D)	Pin 12	
Pin 15	V6 Switch 'closed' (D)	Pin 29	
Pin 29	GND (D) (All digital pins)	Pin 4	Pin 17
Pin 30	V5 Open (D)	Pin 26	Pin 5
Pin 31	V5 Close (D)	Pin 8	Pin 22
Pin 32	V6 Open (D)	Pin 6	
Pin 33	V6 Close (D)	Pin 23	


Input (breakout bord)
X1
Sub-D 37 pin Female
PC1
Sub-D 37 pin Female
PC2
Sub-D 37 pin Female
Output (breakout bord)
BNC 8
Female
BNC 9
Female
BNC 10
Female
BNC 11
Female
BNC 12
Female
BNC 13
Female
BNC 4
Female
BNC 5
Female
BNC 6
Female
BNC 7
Female
BNC 1
Female
BNC 2
Female
BNC 3
Female
Digital I/O dSpace
Sub-D 37 pin Female
Digital I/O dSpace
Sub-D 50 pin Female

Bibliography

[1] Gurski. *Laboratory Setup Three - Tank - System.* Gurski, March 2012.