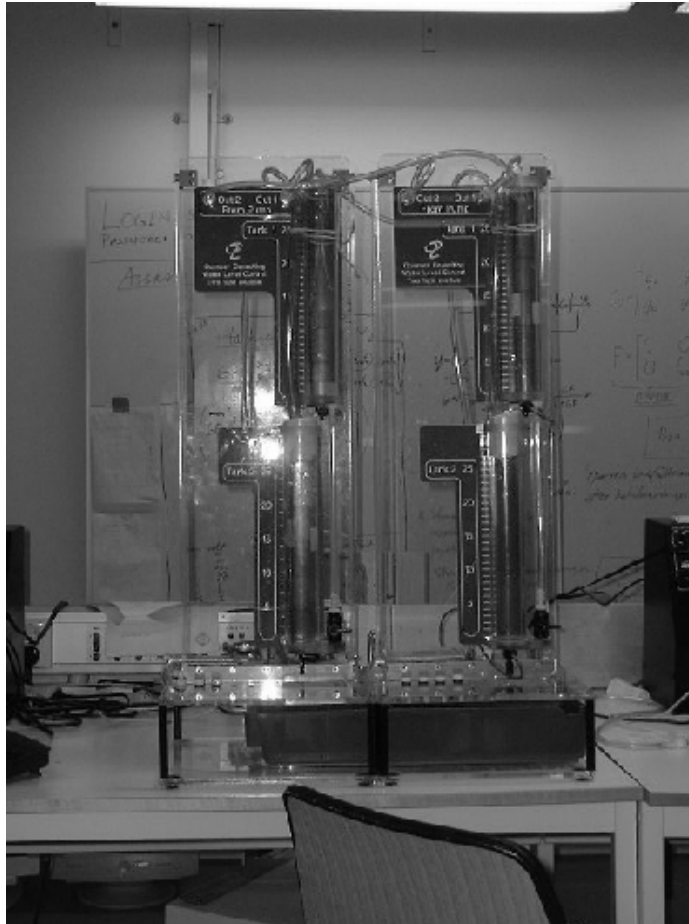




EE – Automatic Control



Control Theory and Practice
Advanced Course

Laboratory experiment: **THE FOUR-TANK PROCESS**

Anders Hansson, Ola Markusson och Magnus Åkerblad, December 1999

Revised by Jonas Wijk December 2002

Revised by Joakim Björk, April 2019

Revised by Yu Wang, April 2020

1 Introduction

In this laboratory experiment we will control the four-tank process, which is a multivariable system. In particular we will investigate interactions between inputs and outputs as well as properties of non-minimum phase dynamics.

The experiment is divided into two occasions. On the first occasion, the modeling and the manual control is performed. This will give you numerical values of some important parameters. Relevant parts of the computer exercises are then repeated, using the identified parameters, to obtain model based controllers. On the second occasion, the control design is evaluated.

Signing up for the laboratory experiment: You should form groups of four students, and then sign up for the laboratory through Canvas. **It is important that you use the correct group number on Canvas throughout the lab, since different group numbers correspond to different models of the four-tank process, and you will use the model obtained on the first occasion for the control design in the second occasion.**

Preparations for occasion 1: Chapters 3.3, 3.5, 3.6, 6.5, 7.3-7.5, 7.7, 8.3, 10.5 in Glad, T. and Ljung, L.: “Control theory—multivariable and nonlinear methods”. Read the lab instructions and solve the problems that can be solved in advance. Also read the Appendix.

Preparations for occasion 2: Four controllers should be prepared and brought to occasion 2. The controllers can be generated through repeating relevant parts of the computer exercises using the parameters identified during lab occasion 1.

One controller for the minimum phase case and one for the non-minimum phase case. In addition to this, construct a robustified controller (for each cases) using the Glover-McFarlane method. Bring the MATLAB scripts and generate the controllers on the lab computer. On page 9 it is described how to name and save the controllers.

Presentation: All problems in this exercise should be solved and be presented in a written report. The date when the report should be handed in is indicated on the course website. The report should be a full report, contain *abstract* and *conclusions*, relevant figures and tables with *captions* and *legends*, etc. Focus on explaining what you have done, and do not repeat theorems but cite them. Remember to write concise (a report is not a novel), be specific in your writing (“the overshoot is 20%” compared to “the overshoot is not so good”), and check your spelling. The report will be graded based on both the content and presentation.

Additional information: Check the course website for additional instructions. Don’t forget to save your data to plot the figures for the report.

2 Laboratory occasion 1

In the exercises below a physical model of the four-tank process will be constructed. Then, we will investigate manual control and coupling between the tanks. Performance

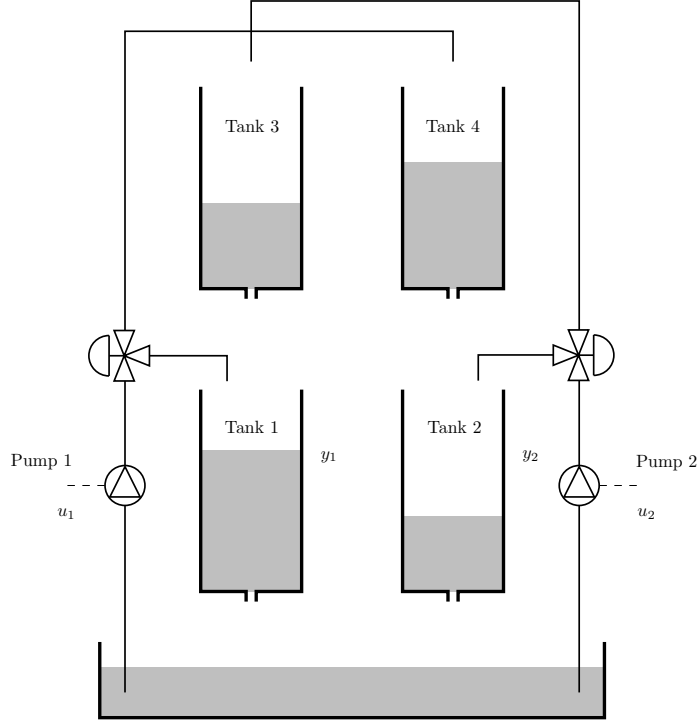


Figure 13: The four-tank process

limitations due to non-minimum dynamics will be investigated. Finally, we will design model based controllers, more specifically decentralized PI control and robust control using the Glover-McFarlane method.

2.1 Modeling

Here the nonlinear differential equations which describe the four-tank process will be derived. The process is shown schematically in Figure 13. For each tank the following relation holds:

$$dV = (q_{in} - q_{out})dt$$

where dV is the change in water volume during the time dt . Divide this equation by dt and assume that $V = Ah$ where A is the cross section area of the tank and h its water level. Then we obtain

$$A \frac{dh}{dt} = q_{in} - q_{out}$$

For the outflow of water, Bernoulli's law holds:

$$q_{out} = a\sqrt{2gh}$$

where a is the cross section area of the outlet hole and $g = 981\text{cm/s}^2$. The flow q generated by a pump is considered proportional to the applied pump voltage u :

$$q = ku$$

where k is the constant. This flow is then divided according to

$$q_L = \gamma ku, \quad q_U = (1 - \gamma)ku, \quad \gamma \in [0, 1]$$

where γ indicates the setting of the valve which is connected to the pump. q_L denotes the flow to the lower tank and q_U is the flow to the upper tank.

Exercise 2.1.1. Show that the following equations describe the water levels in the four tanks.

$$\begin{aligned} \frac{dh_1}{dt} &= -\frac{a_1}{A_1}\sqrt{2gh_1} + \frac{a_3}{A_1}\sqrt{2gh_3} + \frac{\gamma_1 k_1}{A_1}u_1 \\ \frac{dh_2}{dt} &= -\frac{a_2}{A_2}\sqrt{2gh_2} + \frac{a_4}{A_2}\sqrt{2gh_4} + \frac{\gamma_2 k_2}{A_2}u_2 \\ \frac{dh_3}{dt} &= -\frac{a_3}{A_3}\sqrt{2gh_3} + \frac{(1 - \gamma_2)k_2}{A_3}u_2 \\ \frac{dh_4}{dt} &= -\frac{a_4}{A_4}\sqrt{2gh_4} + \frac{(1 - \gamma_1)k_1}{A_4}u_1 \end{aligned}$$

where index i in A_i , a_i and h_i refer to tank i and index j in k_j and γ_j refer to pump j and valve j .

.....

.....

Assume that the levels in the lower tanks are measured by sensors for which the output voltages y_i are proportional to the water levels h_i :

$$y_i = k_c h_i$$

where k_c is a constant.

Exercise 2.1.2. Write down the equations which describe an equilibrium $u_1^0, u_2^0, h_1^0, h_2^0, h_3^0, h_4^0, y_1^0, y_2^0$ for the tanks.

.....

.....

Let $\Delta u_i = u_i - u_i^0$, $\Delta h_i = h_i - h_i^0$ and $\Delta y_i = y_i - y_i^0$ denote the deviations from an equilibrium. Introduce

$$u = \begin{bmatrix} \Delta u_1 \\ \Delta u_2 \end{bmatrix}, \quad x = \begin{bmatrix} \Delta h_1 \\ \Delta h_2 \\ \Delta h_3 \\ \Delta h_4 \end{bmatrix}, \quad y = \begin{bmatrix} \Delta y_1 \\ \Delta y_2 \end{bmatrix}.$$

Exercise 2.1.3. Show that the linearized system is given by

$$\frac{dx}{dt} = \begin{bmatrix} -\frac{1}{T_1} & 0 & \frac{A_3}{A_1 T_3} & 0 \\ 0 & -\frac{1}{T_2} & 0 & \frac{A_4}{A_2 T_4} \\ 0 & 0 & -\frac{1}{T_3} & 0 \\ 0 & 0 & 0 & -\frac{1}{T_4} \end{bmatrix} x + \begin{bmatrix} \frac{\gamma_1 k_1}{A_1} & 0 \\ 0 & \frac{\gamma_2 k_2}{A_2} \\ 0 & \frac{(1-\gamma_2)k_2}{A_3} \\ \frac{(1-\gamma_1)k_1}{A_4} & 0 \end{bmatrix} u$$

$$y = \begin{bmatrix} k_c & 0 & 0 & 0 \\ 0 & k_c & 0 & 0 \end{bmatrix} x$$

where

$$T_i = \frac{A_i}{a_i} \sqrt{\frac{2h_i^0}{g}}.$$

Exercise 2.1.4. Show that the transfer matrix from u to y is given by

$$G(s) = \begin{bmatrix} g_{11}(s) & g_{12}(s) \\ g_{21}(s) & g_{22}(s) \end{bmatrix} = \begin{bmatrix} \frac{\gamma_1 k_1 c_1}{1+sT_1} & \frac{(1-\gamma_2)k_2 c_1}{(1+sT_3)(1+sT_1)} \\ \frac{(1-\gamma_1)k_1 c_2}{(1+sT_4)(1+sT_2)} & \frac{\gamma_2 k_2 c_2}{1+sT_2} \end{bmatrix}$$

where $c_i = T_i k_c / A_i$.

Exercise 2.1.5. The zeros of $G(s)$ are given by the zeros of

$$\det G(s) = \frac{\gamma_1 \gamma_2 k_1 k_2 c_1 c_2}{\prod_{i=1}^4 (1+sT_i)} \left[(1+sT_3)(1+sT_4) - \frac{(1-\gamma_1)(1-\gamma_2)}{\gamma_1 \gamma_2} \right]$$

Show that $G(s)$ is minimum phase if $1 < \gamma_1 + \gamma_2 \leq 2$ and that $G(s)$ is non-minimum phase if $0 < \gamma_1 + \gamma_2 \leq 1$.

Exercise 2.1.6. Show that the RGA of $G(0)$ is given by

$$\begin{bmatrix} \lambda & 1-\lambda \\ 1-\lambda & \lambda \end{bmatrix}$$

where $\lambda = \gamma_1 \gamma_2 / (\gamma_1 + \gamma_2 - 1)$. In the minimum phase case we have $\gamma_1 = \gamma_2 = 0.625$ and in the non-minimum phase case we have $\gamma_1 = \gamma_2 = 1 - 0.625 = 0.375$. Calculate the RGA matrix for both these cases.

All tanks have cross section area $A = 15.52 \text{ cm}^2$. However, their effective outlet hole areas vary slightly, and therefore these have to be determined experimentally. We will use different outlet hole sizes in the upper tanks depending on if we are studying the minimum phase or non-minimum phase case. (The outlet holes in the two lower tanks should always have the same size). This means that we will have to determine six (effective) outlet hole areas altogether.

The level sensors have the proportionality constant $k_c = 0.2 \frac{V}{cm}$. For the minimum phase case, $\gamma_1 = \gamma_2 = 0.625$ and for the non-minimum phase case we have $\gamma_1 = \gamma_2 = 1 - 0.625 = 0.375$.

In order to determine the remaining parameters, $(a_1 \ a_2 \ a_{3,min} \ a_{3,nonmin} \ a_{4,min} \ a_{4,nonmin} \ k_1 \ k_2)$, experiments will be performed.

It is important to prepare proposals for suitable experiments (in order to solve the problems stated below) before performing the laboratory exercise.

Then, in order to perform the experiments, the four-tank process will be set up according to the following instructions:

Note that you should follow the order of instruction strictly, otherwise the simulation result could be wrong.

1. Double-click “lab_start.m” to open the four tank application.
2. Initially a minphase setup is used. You can change this in “SimPara.m”. To set the application to nonminimum phase case, you need to comment the minimum phase part in “SimPara.m”. Note that the parameters in “SimPara.m” are not necessarily the parameters of your model. Additional information on how they are connected physically in water tank lab can be found in appendix A.2.
3. Turn the application to “Simulation” by the switch in the top left corner.
4. Enter your group number on Canvas in “Model no.”.
5. Click the checkbox ‘Uncertainty’.
6. With the controller set to manual mode, choose 50 (% of maximum voltage) of the control signals in the boxes “Input 1/2”, and check that water is pumped into all tanks.
7. Start the simulation by turning the switch in the top left corner from ‘Stop’ to ‘Start’.
8. Additional information on how to use application (such as saving data) can be found in appendix A.3.

The maximum height of each tank is 25 cm; the maximum voltage of each pump is 15V. In the GUI, all measurements, references and inputs are given as percentage of their maximum values.

Exercise 2.1.7. Propose a suitable experiment¹ to determine k_1 and k_2 [$\frac{cm^3}{s \cdot V}$]. Note that you do not need to perform it. **From now on, you can use k_1 , k_2 in the “SimPara.m” as your identified k_1 , k_2 .**

.....

Exercise 2.1.8. Propose a suitable experiment to determine the four effective outlet hole areas a_i for the minimum phase case, and perform it. Note that you need to identify the outlet hole areas from simulations instead of using the parameters a_i in “SimPara.m”, since a_i are different for different groups. (In order to save time, we will determine $a_{3,nonmin}$ and $a_{4,nonmin}$ later.)

.....

2.2 Manual control

Solve the problems below for both the minimum phase and the non-minimum phase case. It is suitable to start with minimum phase.

Exercise 2.2.1. Set the pumps on 50 (% of maximum voltage). Wait until stationarity and read the levels on all four tanks from the scale indicated in cm on the four-tank process. Are the levels (fairly) in accordance with the calculations on the equations in Exercise 2.1.2²?

.....

Exercise 2.2.2. Study the step responses (the two outputs) from one input at a time for the two cases (minimum and non-minimum phase). Does the system seem to be coupled? Is this in accordance with the indications of the RGA?

.....

¹Tip: there might be air in the tubes, even when the pumps are on. Let the water flow and squeeze the tubes carefully to eliminate the air. A good idea is to run the experiment with $u_1=u_2=7.5$ V (50% of maximum voltage).

²The level sensors are not calibrated exactly, and therefore the value you read from the scale does not correspond exactly to the value displayed on the screen.

Exercise 2.2.3. Choose suitable reference levels for the two lower tanks, for example 15 cm (60% of full tank). Try to manually set the pump voltages so that the values displayed on the computer screen become equal to the reference values³. How long is the transient time?

Hint: Patience is required for the non-minimum phase case. (If you have not succeeded after 10 minutes, skip it and move on.)

.....

³Because of the measurement technique, it might happen that the signals from the level sensors are subject to small jumps every now and then, so called “offset jumps”.

1. Switch the system to the non-minimum phase case by changing “Sim-Para.m”.
2. Go back to Exercise 2.1.8 and determine $a_{3,nonmin}$ and $a_{4,nonmin}$.
3. Now repeat the exercises above for the non-minimum phase case.

Exercise 2.2.4. For the above exercises, what are the most important differences between the minimum phase and the non-minimum phase case?

.....

.....

The first laboratory occasion is now completed, but don’t forget to:

1. Motivate your answers clearly in your report.
2. Save your data and figures.
3. Do the preparation tasks for the next laboratory occasion (they are described in the next section.)

3 Calculation of controllers

Before laboratory occasion 2, four controllers will be calculated.

Exercise 3.1.1. The values of the effective outlet hole areas, the k_i and γ_i ($i = 1, 2$) that you obtained will now be used to calculate controllers for the next laboratory occasion. Therefore, change the values in the files `minphase.m` and `nonminphase.m`. Two controllers for the minimum phase case and two for the non-minimum phase case. In each phase-case, the first controller should be the decentralized controller which you thought was the best when performing the computer exercise. Do not forget to motivate your choice. The second controller should be a robustified Glover-McFarlane controller.

.....
.....
.....

The controllers are saved as .MAT files using the function `save` (type `help save` for more information). The controller is saved using its state space matrices. These must be named A , B , C and D . To load the controller, the application must be set to “Feedback” mode. Click “Select Controller Directory” and locate the folder containing your controller. The button “Load Feedback Controller” loads the controller “`regulator_name.mat`” specified on the line above. If the controller is found in the directory, the green lamp indicates that it is loaded.

Note: It is preferred, and a huge advantage, to save a MATLAB script file that generates the controllers in the lab. There are some incompatibilities between different MATLAB versions, and it also lets you recompute the parameters at the second occasion if the four tank process has changed.

If the controller F is available on transfer function form, the following MATLAB code can be used to save it:

```
F=ss(F,'min');  
[A,B,C,D]=ssdata(F);  
save regulator_name.MAT A B C D
```

4 Laboratory occasion 2

4.1 Decentralized control

The exercises below require that you have repeated the design process in the computer exercises with the parameters obtained on the previous lab occasion. Make sure that small step responses and load disturbances do not cause saturation of the control signals. Start by setting up the four-tank process in the following way:

Note that the order of operations should follow the instruction strictly, otherwise the simulation result could be wrong.

1. Double-click “lab_start” to open the four tank application.
2. Set your model as minimum phase or non-minimum phase case by changing “SimPara”. Additional information on how they are connected physically in water tank lab can be found in appendix A.2.
3. Turn the application to “Simulation” by the switch in the top left corner.
4. Enter your group number in “Model no.”. Note that you should use the same group number as in laboratory occasion 1 to specify your model number.
5. Generate and save the four controllers (according to the instructions in section 3).
6. Load the controller according to instructions in appendix A.3.
7. Click the checkbox ‘Uncertainty’.
8. Start the simulation by turning the switch in the top left corner from ‘Stop’ to ‘Start’.⁴
9. Additional information on how to use application (such as saving data) can be found in appendix A.3.

Solve the exercises below for both the minimum phase and non-minimum phase case. It is suitable to start with the minimum phase case.

Exercise 4.1.1. Wait until stationarity. Choose the best decentralized PI controller. Make sure that you work with small deviations from these levels, about 5 percentage points. Investigate the system’s response from a step in one of the reference signals. What is the rise time and the overshoot? Also, investigate the system’s response to different load disturbances, which can be added by clicking the corresponding checkboxes in the left middle corner once: pour a cup of water in one of the lower tanks; open an

⁴It is a good idea to first test the system using manual control.

extra outlet in one of the upper tanks. How long time does it take for the controller to eliminate the load disturbances?

.....
.....
.....

Now change the configuration to the non-minimum phase case according to the instructions above. Then repeat the exercise above for the non-minimum phase case. (Problems can occur when opening an extra outlet in one of the upper tanks. In that case, specify what kind of problems that you get.)

Exercise 4.1.2. For the exercises above, what are the most important differences between the minimum phase and non-minimum phase case?

.....
.....
.....

4.2 Robust control

The exercises below require that you have repeated the design procedures in computer exercise 4 using the parameters obtained previously in this laboratory experiment.

Solve the problems below for both the minimum phase and the non-minimum phase case. We start with the latter by changing the configuration to the non-minimum phase case according to the instructions above.

Exercise 4.2.1. Wait until stationarity. Choose the Glover-McFarlane controller calculated according to the instructions in computer exercise 4. Make sure that you work with small deviations from these levels. Investigate the system's response to a step in one of the reference signals. What is the rise time and the overshoot? Also, investigate responses from different load disturbances, which can be added by clicking the corresponding checkboxes in the left middle corner once: pour a cup of water in one of the lower tanks; open an extra outlet in one of the upper tanks. How long time does it take for the controller to eliminate the load disturbances?

.....
.....
.....

Exercise 4.2.2. What are the most important differences in performance when comparing the different controllers?

.....
.....
.....

Now change the configuration to the minimum phase case according to the instructions above. Then repeat the exercise above for the minimum phase case.

Exercise 4.2.3. For the above exercises, what are the most important differences between the minimum phase and the non-minimum phase case?

.....

.....

The second laboratory occasion is now completed, but don't forget to:

1. Save your data and figures.
2. Motivate each question clearly in your report.
3. Write the report!

A Manual for the four-tank process

This manual is divided into four parts. The first part describes how to connect the process physically. The second describes how to connect the minimum phase and non-minimum phase case. The third part deals with the graphic user interface. The fourth part deals with disconnecting the process. Note that the lab project will not be performed physically in 2020. Therefore, A.1, A.2, and A.4 are not relevant to the lab in 2020. However they give you some information on how the lab is performed physically, which might be good to understand the four-tank process.

A.1 How to connect the components of the four-tank process

The four-tank process consists of two double-tank processes connected to each other. The double-tanks are used for the laboratory experiments in the basic control course. Now we will describe how to connect the components of the four-tank process.

- Find the two double-tank processes that you are going to use. (Your group letter decides which two process that you are going to use, see “Signing up for the laboratory experiment” on page 1.) From now on, we will denote these two process “left” and “right”, as seen from the front. Carefully remove the blue water bowls. Release the right process by disconnecting the two cords connected to it. Carefully put the right process as close to the left process as possible. (Put both processes at the same table, so that there is no differences in altitude between them). On top of the cupboard at the back of the hall, there is a bigger water bowl which you will place under both the two lower tanks. Fill it with water, almost to the top.
- We will only use the computer of the left process, and we will soon connect the measurement and control signals. However, we will use the UPM:s (Universal Power Module) of both processes. There is an I/O card which belongs to the computer, and you find it at the back of the computer. We will use the card’s analogue Input and Output sockets. The left process should already be correctly connected, but to be sure we will verify it. Its control signal ⁵ should be connected to the card’s “Analog Output kanal 0”. Its level sensor for the lower tank⁶ should be connected to the card’s “Analog Input kanal 5”. The remaining three level sensor cords should not be connected. Disconnect the cords which are connected to the I/O card of the right computer (not the broad gray flat band cables). Move the UPM of the right process closer to the left one, so that its cords can be connected to the I/O card of

⁵The black cord which is connected to “From D/A” at the UPM.

⁶The white socket, (marked with 2), at the broad socket with 4 channels which is connected to “To A/D” at the UPM.

the left computer. Connect the control signal of the right process to the card's "Analog Output kanal 1" and the lower tank level sensor of the right process to "Analog input kanal 4". Finally, connect the two non-connected cords ⁷ from the right UPM to the right process. If you are unsure: check once again that you have connected the process correctly!

A.2 Minimum phase and non-minimum phase settings

Depending on which phase case you are working with, you should use different outlet holes of the upper tanks, and connect the cords differently. Below you find a description of this procedure.

For each double-tank process, there are three extra outlet plugs (besides those that are already screwed under the tanks). One located far to the left which has no holes, one in the middle which has a small hole and finally one to the right which has a large hole.

In the minimum phase case, each pump pumps most of the water into "its own" lower tank, and only a smaller fraction of water into the upper tank at the other side. With this setting, we obtain a γ larger than 0.5. In the non-minimum phase case we have the opposite situation, and γ is therefore less than 0.5.

A.2.1 The minimum phase case is connected in the following way

- Put something on top of the two lower tanks, for example a paper towels. (To make sure that nothing falls down into them ⁸.)
- Use the wrench attached to the process to unscrew the plugs under both the upper tanks. Place each screw among the set of extra screws on each process (to the left of the plug located at the far right side).
- Put the small outlet holes in both the upper tanks. It is not necessary to pull tight. (Remember that the processes are fragile.)
- The four tubes, which will be connected according to the instructions below, have to end approximately 27 cm above the bottom of the upper tanks⁹. It is a good idea to pull the tubes through the holes located at the top of the four-tank process, so that the tubes go partly at the back of the process.

⁷The black cord connected to "To Load" at the UPM and the gray cord.

⁸If anything falls into the tanks, one has to disconnect tubes and cords from that process. Then one has to tilt the process very carefully so that the item that fell into the tank falls out.

⁹If the tubes end at different altitudes, the constants k_1 , k_2 , γ_1 and γ_2 can be affected, because the driving force acting on the water is changed.

- Pull the tube from “Out 1” at the left process to the extra plastic pipe next to tank 3, so that its water falls directly into tank 1. (The numbering of the tanks is given in Figure 1 on page 2.)
- Pull the tube from “Out 2” at the left process to tank 4.
- Pull the tube from “Out 1” at the right process to the extra plastic pipe next to tank 4, so that its water falls directly down in tank 2.
- Pull the tube from “Out 2” at the right process to tank 3.

A.2.2 The non-minimum phase setting is obtained in the following way

- Put something on top of the two lower tanks, for example a paper towels. (To make sure that nothing falls down into them).
- Unscrew the plugs located under the two upper tanks. For each process, place the plug among the set of extra screws (to the right of the plug located at the far left side).
- Put the medium size holes in the two upper tanks. It is not necessary to pull tight. (Remember that the processes are fragile.)
- The four tubes, which will be connected according to the instructions below, have to end approximately 27 cm above the bottom of the upper tanks. It is a good idea to pull the tubes through the holes located at the top of the four-tank process, so that the tubes go partly at the back of the process.
- Pull the tube from “Out 2” at the left process to the extra plastic pipe next to tank 3, so that its water flows directly into tank 1.
- Pull the tube from “Out 1” at the left process to tank 4.
- Pull the tube from “Out 2” at the right process to the extra plastic pipe next to tank 4, so that its water falls directly into tank 2.
- Pull the tube from “Out 1” at the right process to tank 3.

A.3 The graphic user interface

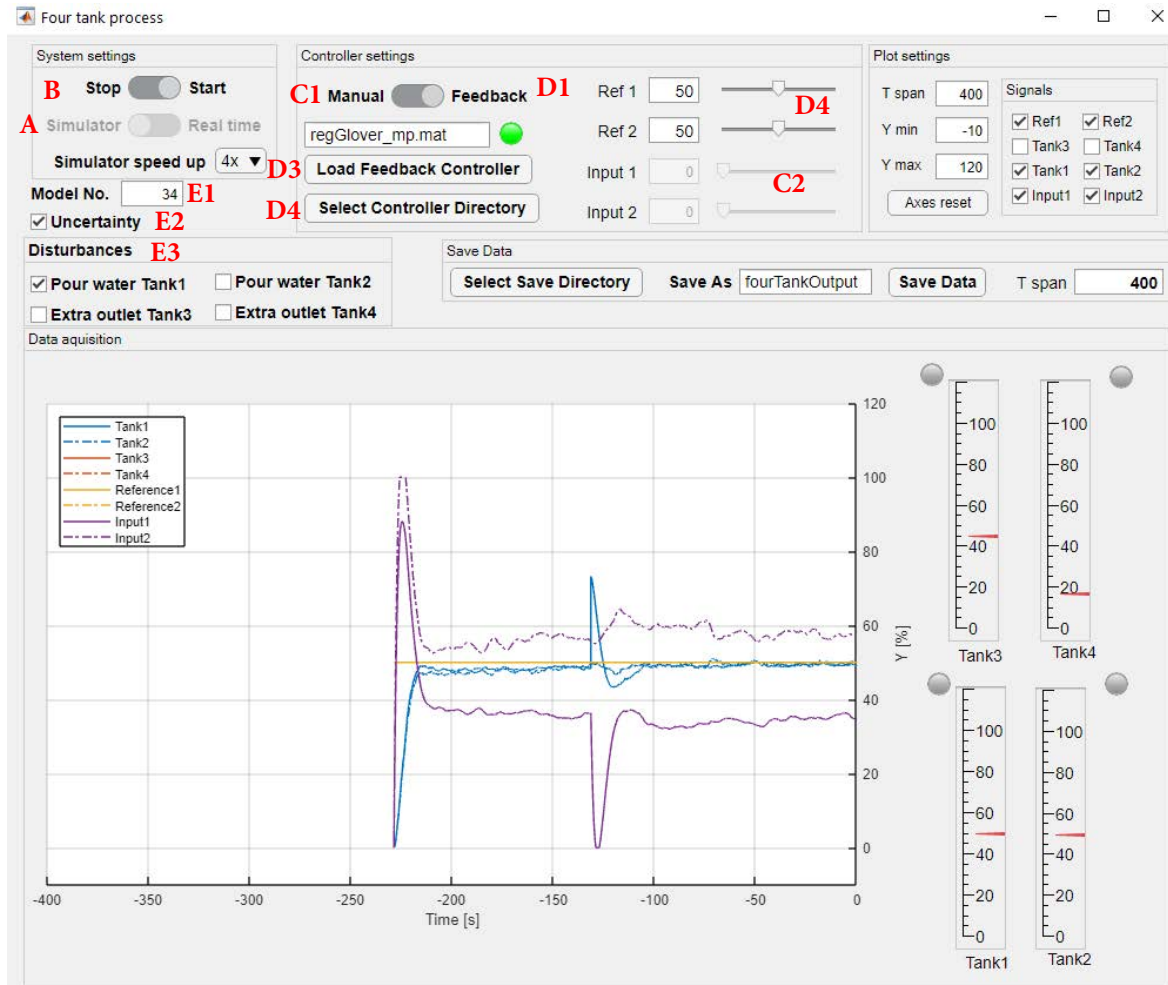


Figure 14: The graphic user interface.

- The interface is opened by running the “lab_start - Fourtank Shortcut” MATLAB script on the desktop.

A Choose between simulation and real time. Note that you can only choose simulation mode. Simulation parameters are loaded from the file SimPara.m available in the same folder as the application. Simulation parameters are loaded on start up. To change parameters, edit and save SimPara.m and reload the application.

B Start/stop pumps (Real time) or start/stop time (Simulation).

C1 Manual control.

C2 Set the control signal (% of total voltage) under manual control.

D1 Feedback control.

- D2 Locate the folder where you controllers are stored. How to save the controllers is described on page 9.
- D3 Load controller written in the field. Controller need to be available in the specified directory. If controller is loaded successfully the indicator will turn green.
- The data is saved in a similar manner. First specify the directory where you want the data to be saved, name the file and click "Save Data". The application will save time, input, tank levels, and reference values as vectors in a .mat file.
- D4 Reference values for the two lower tanks using feedback control.
- E1 Enter your Group number on Canvas as your model number.
- E2 Add uncertainty in the simulation by clicking the check box.
- E3 Add disturbances in the simulation according to the instructions by clicking the corresponding check boxes. Possible disturbances are pouring a cup of water in Tank 1 or Tank 2, and adding extra outlet in Tank 3 or Tank 4.

A.4 How to disconnect the four-tank process

When disconnecting the four-tank process it is very important that the middle size holes are screwed in the upper tanks. Check this, and go through the steps below:

1. Empty the large water bowl and put it on top of the cupboard at the back of the hall.
2. Disconnect the tubes between two double-tank processes.
3. Make sure that no tube is connected to “Out 2”.
4. Connect a tube to “Out 1”, put it through some hole so that it comes out at the back of the process, and then through the hole which is just above the upper tank. Then put the tube into the upper tank. Do this for both processes.
5. Remove the cables of the right UPM from the I/O card of the left computer. Also, disconnect the right process by disconnecting the two cords connected to it.
6. Put back each process (with its UPM) at its original spot and put a blue water bowl under each double-tank process.
7. Connect the level sensors to each tank¹⁰ at the card’s “Analog Input kanal 4” and “Analog Input kanal 5” respectively. (The yellow at 4 and the white at 5.)
8. Connect each control signal¹¹ to “Analog Output kanal 0” at each I/O card.
9. Finally, connect the two non-connected cords¹² from the right UPM to the right process.

¹⁰The yellow and white sockets, (marked with 1 and 2 respectively), at the broad cord with 4 channels connected to “To A/D” at the UPM

¹¹The black cord connected to “From D/A” at the UPM.

¹²The black cord connected to “To Load” at the UPM and the gray cord.