Laboratory 1
Control of a water level in a tank

1 Preliminary : rules regarding the Covid-19

Please follow carefully the rules mentioned on the website of the UCLouvain: `https://uclouvain.be/fr/decouvrir/mesures-prises-a-l-uclouvain-dans-le-cadre-de-la-covid-19.html`.
The tables of the laboratory enable to keep the distance of $1,5$ m between students. Here is a procedure to follow to maximize the health safety while performing the laboratory inside the Euler building:

- Always wear the face mask inside the Euler building;
- Clean your hands with the hydro-alcoholic gel (a dispenser is placed in the corridor);
- Clean your work table with the antistatic cleaning lotion (a dispenser is placed inside the laboratory);
- Clean the keyboard and the mouse of the computer with the IPA (Isopropylic Alcohol) aerosol before starting to work.
- When you finish your work, please clean your work environment with the antistatic cleaning lotion and the keyboard and mouse of the PC with the IPA aerosol before leaving.

For your information, there are toilets where you can wash your hands with soap at both ends of the corridor of the -1 level of the Euler building.

In addition, regarding its own organization, every team of student has to manage any possible impact of a quarantine for one or more student in the team...

2 Introduction

This first laboratory deals with the control of the water level in a tank feed with an adjustable flow. The teams of 2 students have 2 time slots of 2 hours (i.e. 4 hours) to perform the experimental part of the laboratory. The second lab should only be started once the first one is completed, and reservation of time slot is only possible then.

In this document, the equipment (i.e. hydraulic, electrical and software) and the modeling of the system are presented first, and the instruction for the experiments to conduct are in section 5.

As a reminder, the mastery of the document titled ***General manual for the labs and the tutorials sessions*** is a **prerequisite for performing the laboratories**.

3 Equipment overview

The laboratory's equipment consists of three distinct parts:

- The hydraulic part, including a collecting tank, two diaphragm pumps, each driven by a DC motor and three cylindrical tanks;
- The electrical control, power and interface system;
- One PC that runs a software that controls the system.

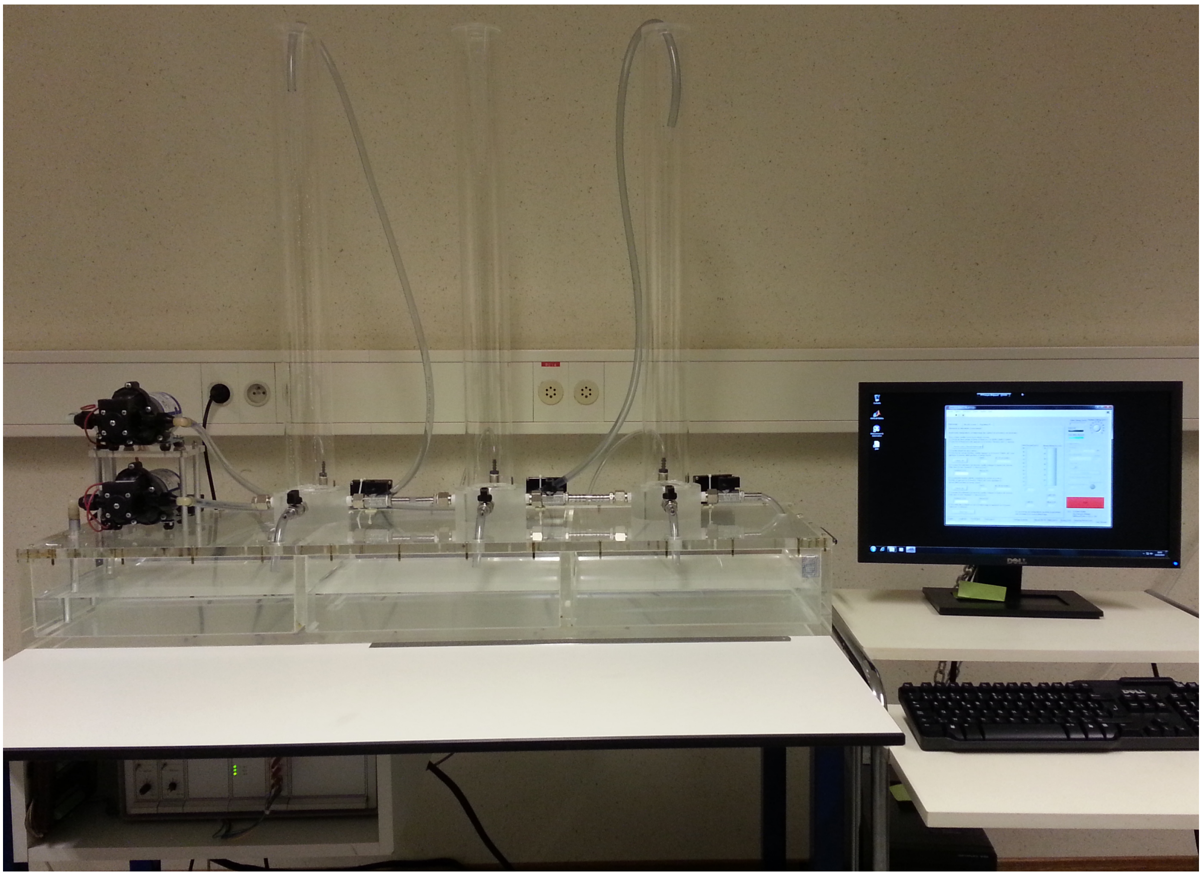

Figure 1: 3 tanks system for the first laboratory

3.1 The hydraulic process

In more details, the hydraulic process includes:

- Three water tanks (numbered from 1 to 3, from left to right) and one collecting tank;
- Manual valves to interconnect the tanks. These valves are identified with indices compounds by capital letters S (side) or F (front) and numbers (indicating the tanks between which the valve is a connection; the collecting tank is numbered 0). The valves are in the open position when the body of the handle is parallel to the direction of the flow. To close the valves, you have to carefully turn the black handle a quarter turn clockwise (this movement does not require much strength : **do not force on the handle**);
- One differential pressure sensor by cylindrical tank. This sensor measures the pressure of the water column in the vertical tank;
- Two diaphragm pumps that ensure the water flow from the collector to the cylindrical tanks. The flow rate of the pumps are controlled by electrical signals applied to drive the DC motor.

3.2 Restrictions of use

In this laboratory, only the tank 3 (i.e. on the right) and the pump 1 will be used.

3.3 The electrical circuit

All the electrical and electronic equipment are put beneath the table that supports the hydraulic process.

The electrical circuit provides 4 functions:

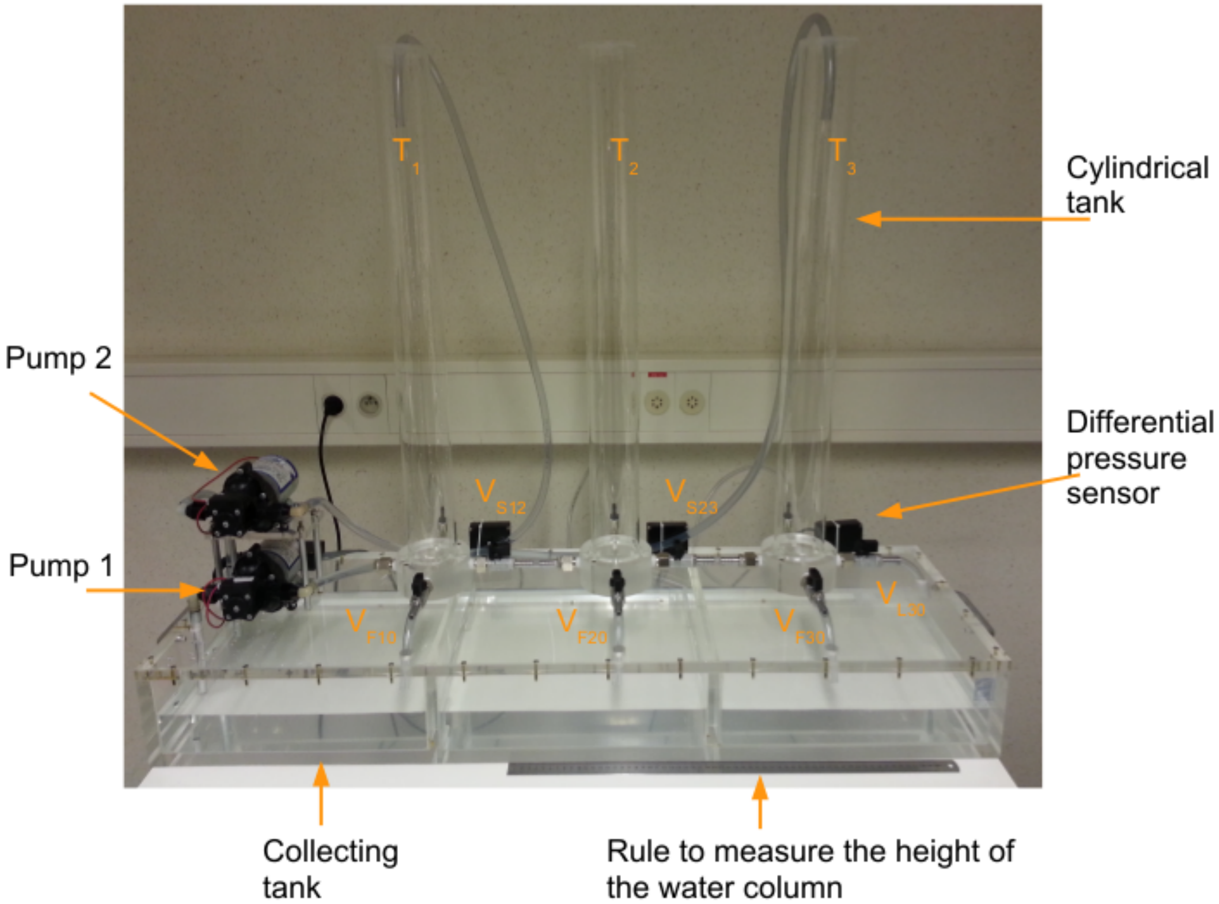

Figure 2: Hydraulic process of the lab.

- The power supply of the different components;
- The local control of the pumps flow rates;
- The shaping of the analog electrical signals from the sensors;
- The conversion of the information of analog signals into computer messages (transmitted by USB).

Before any laboratory, the user have to ensure that:

1. The main electrical box is on;
2. The 2 electrical switches (on the front of the box containing the electronic circuit) that determine the control of the water pumps are turned on "`Automatic`". For information, the "`Manual`" mode enables the user to set the power of the pumps with the small black potentiometer (if this mode is selected, the PC is unable to control the pumps).

For more precision the front face of the electrical box should be identical as shown on the figure 3 (position of the switches, connections of the wires and ideally states of the LEDs). If some LEDs are not lit, it means that the internal electronic calibration could be passed, but normally that will not affect the results of the experiments.

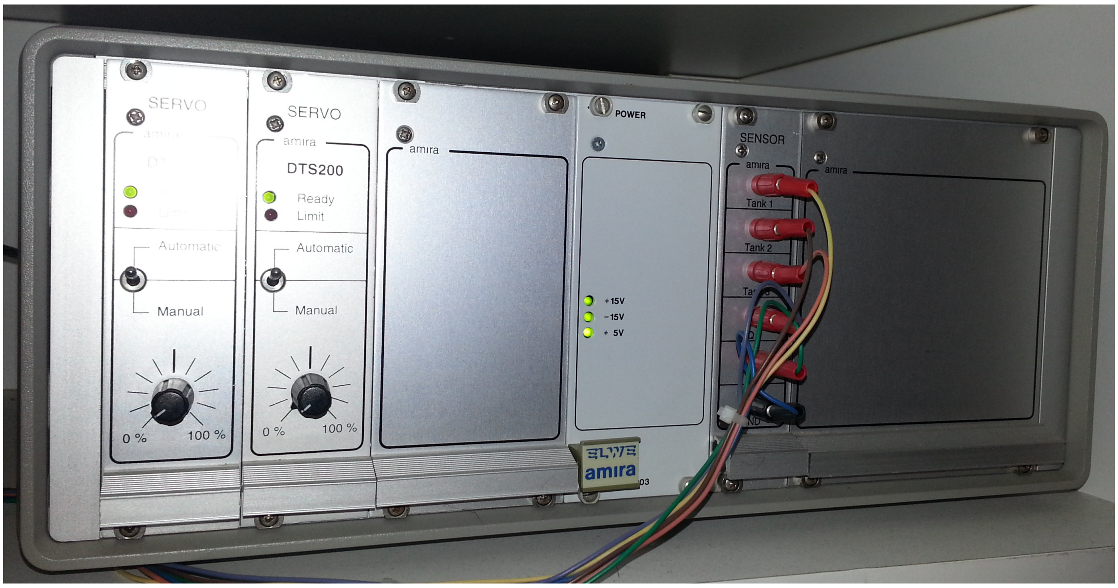

Figure 3: Appropriate settings and connections of the electrical part to perform the lab.

3.4 The control and supervision software

The control and supervision software has been developed with the National Instruments LabVIEW integrated development environment.

This sofware provided for this lab contains 3 tabs for:

1. The calibration of the sensors and the actuators;
2. Perform test in open loop with the system;
3. Perform test in closed loop with proportional and integral controllers.

Every tab window included a set of instructions that has to be sequentially followed to perform the experiments described in this laboratory.

3.4.1 Overview

The big red push button `STOP - EXIT` is used as an emergency stop push button. It resets all the actuators (forces all the flows to 0) and exit the software. The coefficients computed during the calibration process are lost.

At the end of the session, to properly exit the software, the students have to maintain pushed the red `STOP - EXIT` push button several milliseconds to reset the internal commands of the program.

In general, if the manipulated elements (buttons, dials, controls, graphs) appear inactive, it means that they are, and that some steps have been deleted.

The execution of the tabs *Open Loop* and *PI controller* is disabled if the calibration process has not been properly run and the LED `System calibrated ?` is not green.

A counter overflow safety has been programmed. If the pressure sensor detects a height of water greater or equal to 60 cm, the `Overflow warning` LED pass from green to red and resets the flows from the pumps. In the case of a water height greater to 70 cm, the counter overflow software safety reset the actuators and exit the program. It is then necessary to empty the cylindrical tank and make the calibration of the sensors and actuators.

3.4.2 *Calibration* tab

At each start of the program, the user has to begin with the calibration of the sensors and actuators with this first tab.

The goal is to calibrate the water level sensor (of the third tank) which is based on a differential pressure sensor (pressure of the bottom of the tank - atmospheric pressure), and the flow rate from the water pump.

When the elements of this tab are running, the recording window is disabled because recording data is needless (see Fig. 4).

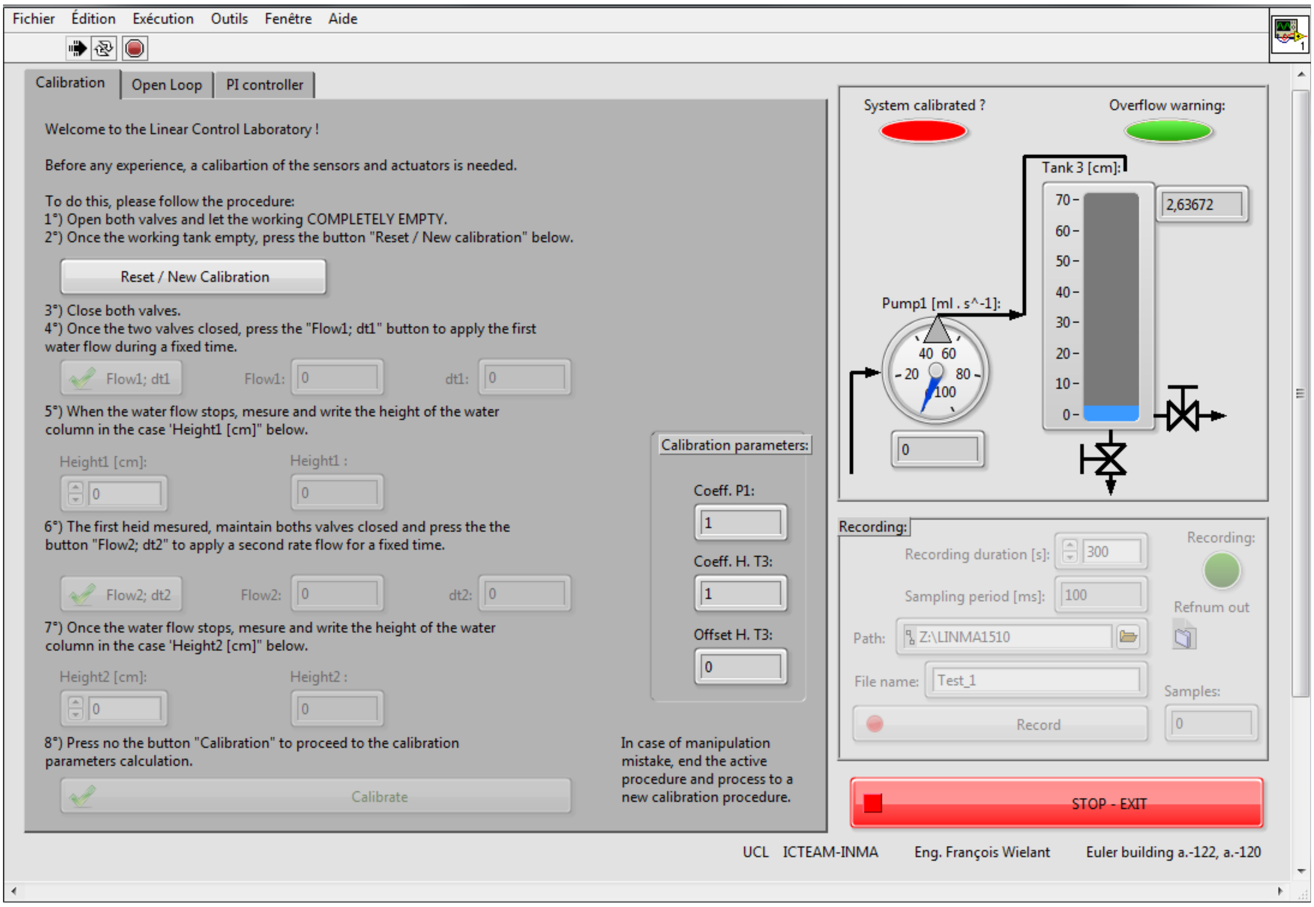

Figure 4: Supervision screen of the calibration of the sensor and actuator

3.4.3 *Open Loop* tab

This tab allows to perform a step response on the system in open loop.

It enables to position the system at an operating point around which may be considered as being linear, and also to validate the analytically computed transfer function of the system.

The recording of the data in a text file on the path `Z:\LINMA1510` will allow to process the experimental data later.

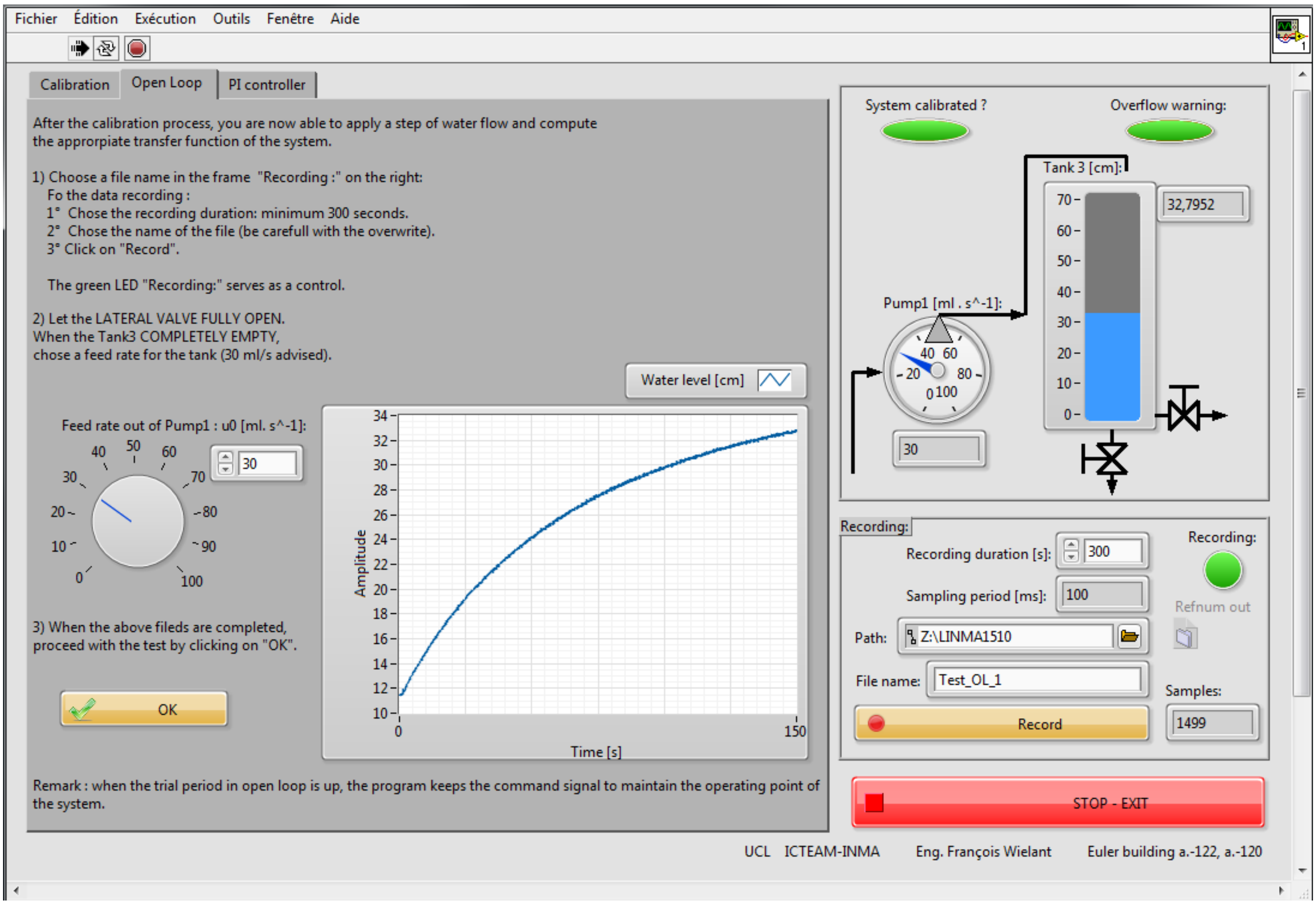

Figure 5: Supervision screen to test the system in open loop

3.4.4 *PI Controller* tab

This tab will be used to test a Proportional and Integral controller.

From the *Open Loop* tab, when the system is on its operating-equilibrium point (in open loop so), the user can close the feedback loop by clicking on this tab (the open loop command is maintained until the controller is started).

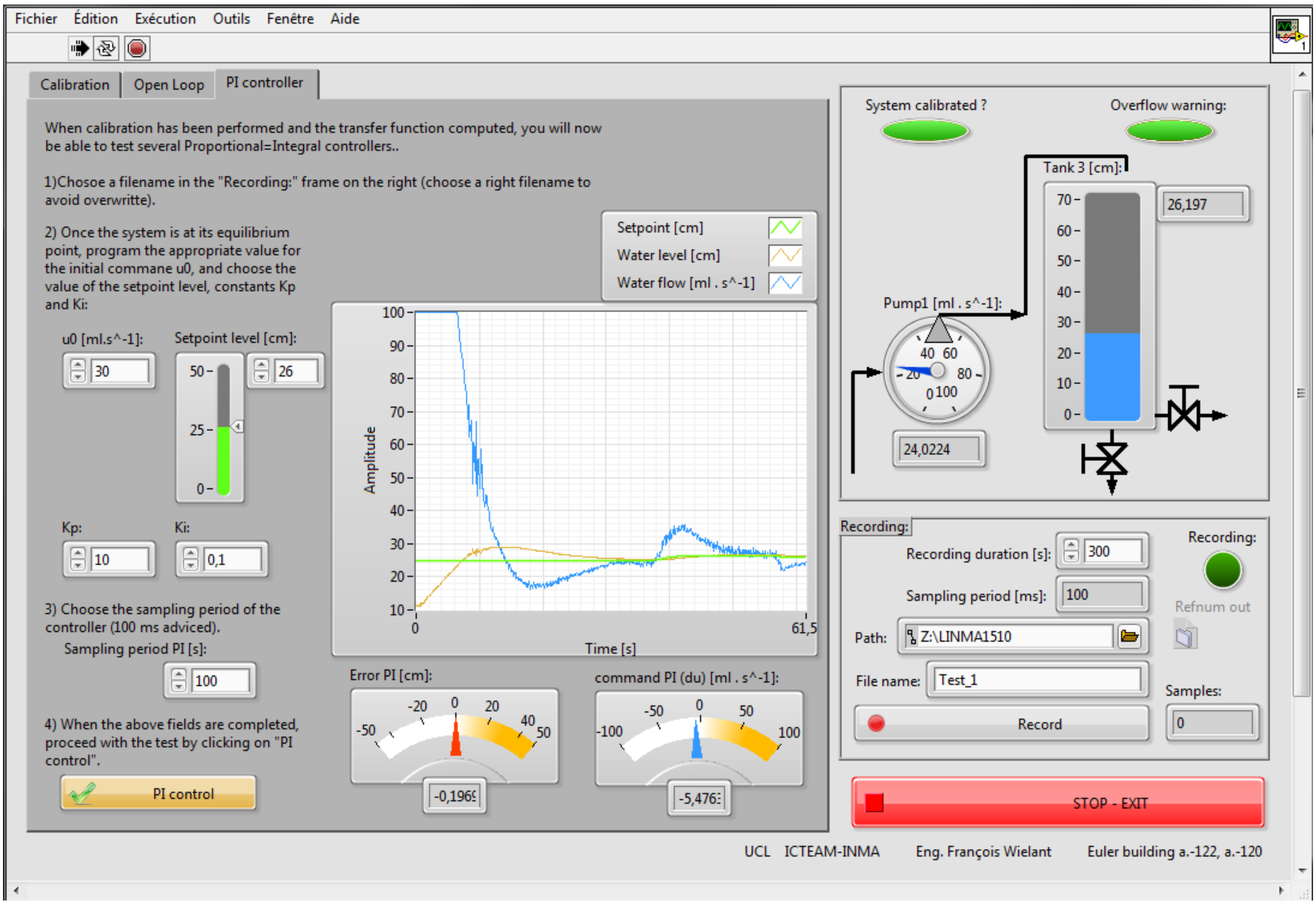

Figure 6: Supervision screen of the software to test the PI controllers

4 Mathematical model of the system

4.1 Notation

S ou F	Side or Front; space position of a valve or a flow rate.		
h_x	Height of the water column in the tank x.	$[0;60]$	$[cm]$
q_{Sxy}	Side flow rate from the tank x to y.		$[ml.s^{-1}]$
q_{Fxy}	Front flow rate between from the tank x to y.		$[ml.s^{-1}]$
q_{Px}	Feed rate from the pump to the tank x.	$[0;100]$	$[ml.s^{-1}]$
S_{Sxy}	Surface of the side valve connecting the tanks x and y.		$[cm^2]$
S_{Fxy}	Surface of the front valve connecting the tanks x and y.		$[cm^2]$
S_R	Surface of the cylindrical tank.	43	$[cm^2]$
g	Gravity constant.	981	$[cm.s^{-2}]$

4.2 Modeling

The used model is nonlinear and comes from the Bernoulli's equations of conservation of energy. This model does not consider the fluid viscosity, and the local turbulence phenomenon.

In this lab, the side valve connecting T_2 and T_3 will always be closed ($S_{S23} = 0$), so the flow q_{S23} is always equal to zero.

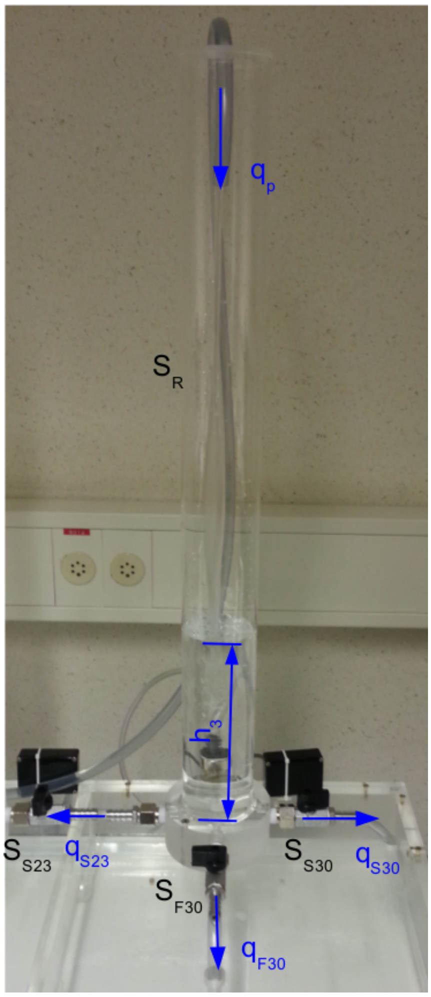

Figure 7: Parameters and state variables of the system.

The model uses two principles:

- Continuity equation:

$$\frac{dh_3}{dt} = \frac{1}{S_R} q_{P3} - \frac{1}{S_R}(q_{F30} + q_{S30})$$

- Flow model (Toricelli's law):

$$q_{F30} = S_{F30}\sqrt{2gh_3}$$
$$q_{S30} = S_{S30}\sqrt{2gh_3}$$

5 Experiments

To drive the pump-tank system from the PC, download in this notice) and then execute the software `Tank_Level_Control_2018_vX.exe` available on *Moodle* (store it in your network disk names `Z:\`.

For the experiments of this lab, you only have to use the third tank (on the right). The valve configuration is as follow:

- Valve V_{S23} always closed, for all this lab.;
- Valve V_{F30} normally closed, except other indication (open to cause disturbance);
- Valve V_{S30} always open.

Before any experiment, it is recommended to check if the flexible pipe connecting the pump 1 and the tank 3 is full of water (to avoid an initial error in the calibration procedure).

5.1 Calibration

As mentioned before, from the start of the application `Tank_Level_Control_2020_vX.exe`, it is necessary to calibrate the sensor for measuring h_3 and the water flow rate from the pump 1 q_{P3} before any experiment.

Performing this function computes three parameters that will be stored during the execution of the software:

- A proportionality coefficient to adjust the flow rate from the pump;
- A proportionality coefficient to correct the measure of the water column's height h_3;
- An offset parameter to correct the measure of h_3.

If the user ckicks on the `STOP - EXIT` push button, the program exits and these 3 parameters are lost. A new calibration has to be performed to recalculate the parameters.

5.2 Open loop experiment

Once the calibration process is done, users can use the *Open Loop* tab and perform the following tabs:

1. Set a recording duration (at least 250 seconds);
2. Set a flow rate $q_{P3} = u_0$ of 30 $[ml.s^{-1}]$;
3. Once the water level is stable (i.e. the equilibrium point is reached), write down the value of $\bar{h}_3$;
4. Compute the value of the surface S_{S30} of the side valve;
5. Linearize the model around the equilibrium point and get the transfer functions of the system $G(s) \equiv q_{P3} \rightarrow h_3$ and $H(s) \equiv S_{F30} \rightarrow h_3$.

5.3 Closed Loop experiments (PI Controller)

The controller programmed in the software is a Proportional and Integral controller, and its model is shown on figure 8.

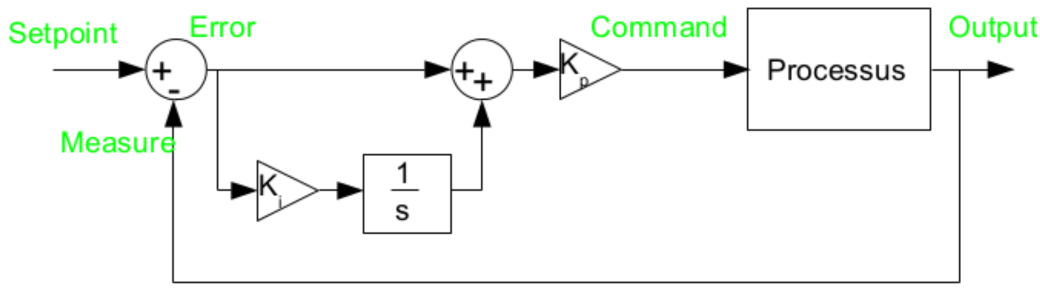

Figure 8: Block diagram of the lab. system controlled with a PI controller.

For this laboratory, it is proposed to:

1. Maintain the system in open loop at its natural equilibrium point (perform with the test in the `Open Loop` test);

2. In the tab `PI Controller`, set the recording parameter, then set the control input u_0 and septoint at the level $\bar{h_3}$ found at the previous point;

3. Set the values of the controller's constants: $K_P = 2,5$ and $K_I = 2$ and start the controller.

In this configuration, the system is (poorly) controlled!

5.4 Response of the controlled system with a disturbance

One of the major contribution of the feedback systems is that we can make the controlled system rather insensitive to some disturbances. This point, it will be possible to observe the system's behavior with a variation of the front valve (i.e. an additional leakage flow), and that for 3 sets of the controller parameters.

The 3 settings proposed for analysis are:

$$\{K_P; K_I\} = \{10; 0\}\,; \{3; 1\}\,; \{10; 0,1\}$$

For each of these settings, it is asked to observe the controlled system behavior, to record the data of the experiments and to carefully write down the data of the experimental conditions.

5.5 Response of the controlled system with a step of setpoint

An other benefit of the feedback system is that we can follow the variation of the setpoint in a way that may vary in terms of convergence speed and accuracy.

The goal is to compute the controller parameters $\{K_P; K_I\}$ to get a setpoint step response without overshoot. It is also necessary that the controlled system will be three times faster than the natural system (not controlled) (avoid the steps of too large amplitude, a few are enough).

6 Practical informations

- The 3 systems are located in the Euler building, local a.-103. Given the Covid 19, only one (identified with a banner) is available (to limit the number of 6 students MAXIMUM in the same time inside the local);
- The code to enter the local is **47429**;
- Record data only in your network disk `Z:\`;
- Before leaving the workbench, do not forget to shut down you computer AND to **UNPLUG** the power cord of the 3 tanks system;
- Please keep clean the work environment, including the PC.

7 Assessment preparation

For the lab assessment, it is necessary to perform the test with the software `Tank_Level_Control_2018_eval_vx.exe` (that will be available on *Moodle* a few weeks before the S13 week). This software requires the FGS number of the student, asks randomly selected questions and returns a numerical key. This **personal key is needed for the individual lab assessment**.

Moreover, to be better prepared for this assessment at the end of the course, it is advised to understand and prepare replies to the following statements:

1. Explain the chosen values for $\bar{q_{P1}}$ and $\bar{h_3}$. Explain the calculation of the surface S_{S30};
2. Detail the linearized model of the system and the transfer functions of $G(s)$ and $H(s)$;
3. Compute the closed loop transfer functions $G_1(s)$ and $G_2(s)$;
4. Analyze the performances of several controllers with a front valve opening (disturbance). This includes:
   - The calculation of the time response of the closed loop system with a step of disturbance;
   - The calculation of the amplitude of the error due to the disturbance reaches its maximum for each setting of the controller $\{K_P; K_I\}$;
   - The calculation of the settling time of the system for every setting of the controller;
   - A graphical representation of the theoretical response computed with MATLAB;
   - A comparison between theory and experiments.
5. Compare the time responses of the linearized and the non linear models (that students can compute with the `ODE45` *Matlab* function);
6. The calculation of the parameters $\{K_P; K_I\}$ of a controller to satisfy some specifications for a setpoint step response, and compare theory and experimental results;
7. The answer of the question: What are the nonlinearities on this controlled system (+ brief descriptions and explanations)?