A study into liquid level sensors and the hysteresis principle

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Abstract

The purpose of this project is to achieve automation in a water tank so that the water level could be kept between two levels. The main application of this system is in industrial areas where a constant supply of water is needed and the lack of such a system can lead to a lot of time loss in order to fill the tank again. Moreover, a leakage can be a serious hassle especially in nuclear power plants or in the chemical industry.

This automation will be achieved by controlling the electrical valves, so when the water level exceeds the maximum level, the inflow valve will close and the outflow valve will open and vice versa.

To determine the water level we will use an ultrasonic sensor, but for safety, two water flow sensors will be placed in the tank to determine the velocity of the water flow in order to determine the rate of depletion/repletion in the tank.

Content

Introduction

In modern times, more and more systems are becoming automated due to the necessity of improved productivity and quality over the product. We can find automated systems almost everywhere nowadays, in the automobile industry, chemical, pharmaceutical industry and even in the banking industry.

Automation is clearly a step forward when it comes to productivity, robustness and quality in modern times. This is one of the reasons this project is focused on building an automated water tank, to learn more about automation and how sensors work.

This project is focused on the automation of a water tank that is capable of keeping the water level between two levels (a minimum level and a maximum one) by controlling the electrical valves. When the water level reaches the maximum level, the inflow valve closes and the outflow valve opens and when the water level is too low, the outflow valve closes and the inflow valve opens.

This automated water tank has a lot of industrial application, especially in the chemical and petroleum industry where possible outflows can be costly and dangerous, although this can be an upgrade for the system as we have decided to focus mainly on water tanks.

For the automation process, two sensors will be used: ultrasonic sensor and water flow sensor as a way to determine velocity and for increased accuracy. These two sensors will dictate the water level at all times and the water level will be shown on an LCD. The LCD will show the water level in percentages, the inflow and outflow rate, depletion time of the tank as well as the current state of the valves .

Although there are a lot of types of tanks on the market (each of them with different purposes and sizes), this system is applicable to all of them for the permanent automation of water tanks. For this project we have decided to focus mainly on elevated water tanks, storage water tanks and fire water tanks.

Problem Analysis

In assessing the problem of water level sensing, it must be noted that the topic is a very wide one comprising of many different sensor technologies and applications. Therefore a broader study of its applications, including the 6Ws directed toward the industries where such applications are used and those where they could be used with the purpose to determine where the introduction of such a system could be of benefit.

Liquid level sensing is used mainly for chemical processes, where the level of reactants, reaction chambers and the flow of reactants and products are of interest. In such chemical plants the solutions derived from liquid level sensing vary substantially from process to process, thus making it harder to pin down one specific industry when analysing this problem. Therefore a broader look into the applications should yield an understanding of the different types of sensors and which scenarios they are most apt in.

One such industrial application is Firewater tanks. Firewater tanks are used mainly as a protection mechanism designed to combat incidental situations. The main idea is that a large amount of water be kept in-case of fire, their use is especially prevalent in industries which are more prone to fire related risks, such as oil refineries or large industrial facilities.[1] Considering most industries use heat somewhere along in the process, firewater tanks have become a commonly used risk reduction tool.

Water level in large tanks is a challenge due to inability to directly visualise it. Size is an impediment, as well as the materials that are used. To solve problems related to monitoring the water level, outgoing water flow and feeding the tank from water reserves requires a level of automation. By introducing automation, water can be kept within certain levels more efficiently, eliminating direct human intervention for most of the processes related to this issue. Tanks can come in varied shapes and configurations, and can be divided as follows.

By purpose:

1. Rainwater Tanks
2. Industrial Tanks
3. Potable Water Tanks/Water Tower
4. Fire fighting Tanks
5. Septic Tanks

By content:

1. Water Tower/Water Tanks
2. Chemical basins and tanks
3. Gas and petrol tanks

By location:

1. Above ground
2. Underground
3. Under the water
4. Mobile
5. Semi-mobile

By material:

1. Plastic
2. Galvanized Steel
3. Concrete
4. Specialized materials

In this project, the focus of attention will be on tanks used for water, mainly for fire fighting purposes, but also that can be used in agricultural purposes, water that does not need special treatment.

There is a lack of research conducted on exactly how useful they are as different areas have different needs. Some places have very good water networking and therefore may not even require them, however in more remote areas or places with poorer infrastructure a firewater tank could very easily find its way to being the only available source of water in the case of an emergency. In such a situation a reliable system would be vital.

Another application is, perhaps a more broader one, the use of any chemical process which requires liquid reactants to be mixed from reservoirs to reaction chambers. The flow of these liquids, which is of interest, can be found with changes in the level of the liquid and by use of flow sensors. In certain industries where the reactants may be corrosive an ultrasonic sensor is generally used as the sensor need not be in contact with the liquid. Pressure sensors can also achieve this result for less harmful chemicals.

Looking strictly at tanks used for water, the Government of Newfoundland & Labrador, Department of Environment and Conservation, Water Resources Management Division divides them as follows (1):

1. ***Elevated*** – a water tank supported by a steel or concrete tower that does not form part of the storage volume.
2. ***Standpipe*** – a water tank that is located on the ground surface and has a greater height than diameter.
3. ***Reservoir (Ground)*** – a water tank that is located on the ground where the width/diameter is greater than the height.
4. ***In-Ground (Buried)*** – a water storage tank that is partially or totally below the nominal surface of the ground.

A further tank classification, accordingly to the same source, is whether or not it "floats the system" (1). A tank is said to float on the system if the hydraulic grade elevation inside the tank is the same as the hydraulic grade line (HGL) in the water distribution system immediately outside of the tank. With tanks, there are really three situations that can be encountered:

1. Tank that floats on the system with a free surface.
2. Pressure (hydro-pneumatic) tank that floats on the system.
3. Pumped storage in which water must be pumped from a tank.

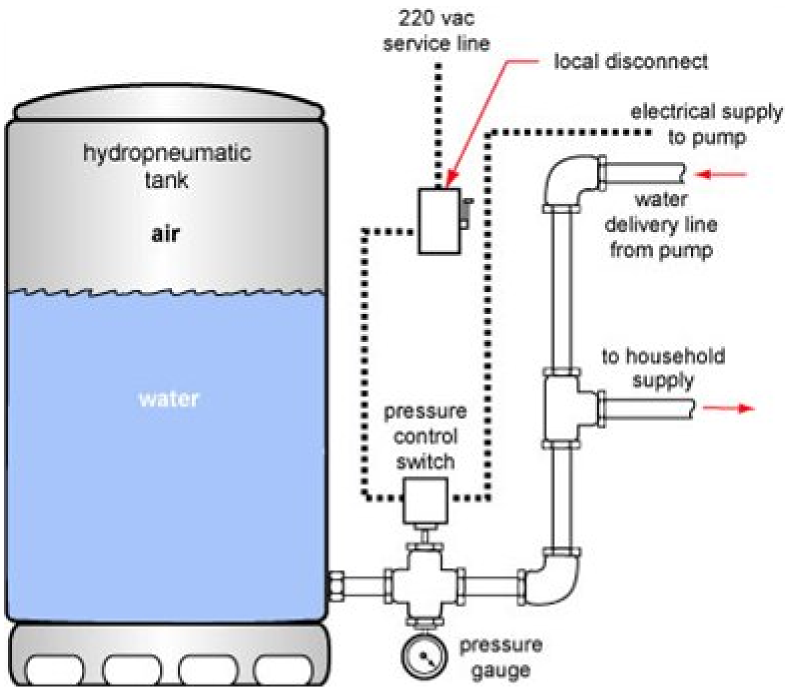

Figure 1- Pressure (hydro-pneumatic) tank that floats on the system. (2)

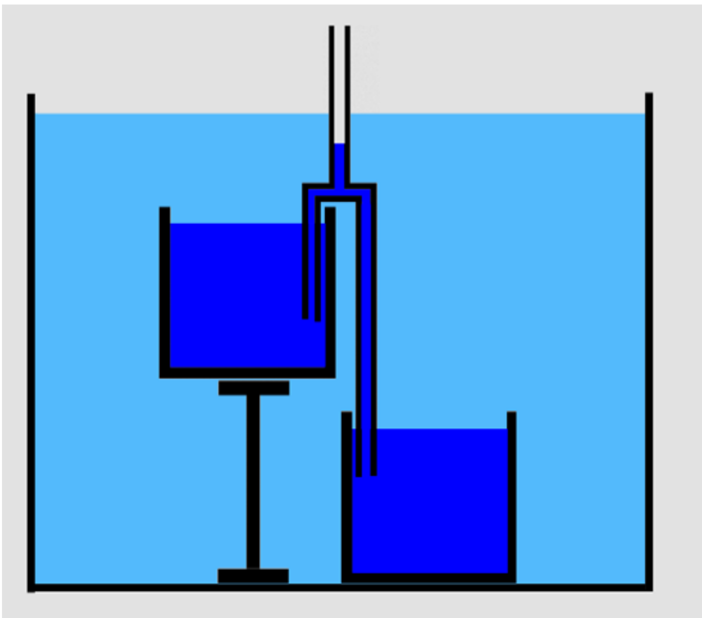

Figure 2- Pumped storage in which water must be pumped from a tank (3)

'What' is the problem?

The problem of water level in tanks arises from the need to always have a reserve volume of water for either regular agricultural and residential needs or for emergency situations when the available water flow will not ensure effective fire fighting. With a volume of water in reserve stocked in large water tanks, for a finite amount of time, a higher water flow can be developed. The time the systems remain inactive is used solely to replenish the tanks. The time the system is active the total depletion time can be drastically reduced by continuously feeding water (total depletion time will be a function of total volume, outgoing water flow and feeding water flow)

'Who' is the problem? (The industries that it relates to).

Stable water levels are required in various industries were water is part of the industrial process, alongside of numerous uses in other fields like chemical industry, energy industry, construction (where maybe semi-mobile tanks are required), agriculture and fire fighting

'Why' do we have a problem?

1. Low water level.
2. Overflow.
3. System failure.

'When' do we have a problem? (When the outflow rate is much bigger than the inflow rate. In this situation the depletion time is very short.)

In particular cases like fire control, higher pressure is needed to effectively control/put off the fire. In other cases the relative height of exit point is higher or at the same level as the water tank and in such cases no water flow can be achieved in the system. According to Bernoulli's principle $P + 1/2\rho V\hat{}2 + \rho gh = constant$, where "*v*" is the velocity of the fluid at the reference point (in this case the hose), "*g*" is the gravitational acceleration, "*h*" is the elevation from the reference point, "*p*" is the pressure at the reference point and "*ρ*" is the density of the fluid in the whole system, and where "*gh*" is generally named force potential and depends on the geography of the location and its elevation.

Pressure can be obtained in 2 ways: pressurizing the tank or elevating the tank to ensure higher potential energy thus higher pressure.
Locations that are not geographically suitable to generating potential energy through direct elevation difference will require either pressurization or elevation difference (water towers or elevated water tanks).

There are cases when not enough volume of water is provided in places where the debit of supplied water is very small, and needs to be supplemented with rain water, or the tank is completely fed with rain water; in such cases a series of tanks could be a solution with the overflow pipe of one tank feeding another tank.

For various situations a large volume of water is needed in a short timeframe so the draining time is very short. A water tank or a series of water tanks offers a buffer volume of water that increases total time of depletion.

'Where' is it a problem?

1. ***Industrial areas:*** industrial processes
2. ***Communities:*** low or fluctuating flow of the main water source
3. ***Forestry:*** low or fluctuating flow of the main water source
4. ***Agriculture:*** low or fluctuating flow of the main water source

An important aspect is fire fighting. Effective fire fighting requires minimal pressure. Keeping the water level between certain levels is a problem especially in the industries where a lot of amount of water is required. Keeping the water level between certain levels using level sensors and automatically controlling the inflow and outflow of water by programming the electrical valves to open and close when water reaches a certain level can save a lot of time before the tank is filled with water again and can guarantee a constant supply of water for the different processes needed. The process of keeping the water between two levels is fully automated so the chance of a human error is inexistent(although system failures can still occur). The most well known incident that implies a human error is the leakage of 100 tonnes of highly radioactively water from a storage water tank at the Fukushima Nuclear Plant (4) (5). The incident was caused because a valve was accidentaly left open.

Firstly, the nuclear industry is an area where a huge amount of water is used for extracting and processing uranium fuel for the production of electricity.As it is stated on a governmental website: „During an accident, a UHP may need to supply 10,000 to 30,000 gallons of water per minute for emergency cooling." (6)

Secondly, a large amount of water is used in irrigation crops aș well: „A large part, about 39 percent, of all the fresh water used in the United States goes to irrigate crops. After use, much of this water cannot be reused because so much of it evaporates and transpires in the fields." (7) (accordingly to a governmental website). It is important to not waste water when it comes to irrigation because this can lead in time to overdrafting (depletion of the water aquifers). Furthermore, this system can help improve the irrigation system. By setting the outflow level of the water, underirrigation and overirrigation can be avoided.

Moreover, this sytem is also designed for fire water tanks in the industrial areas. In the case of an eventual fire in a chemical or petroleum plants, a huge amount of water is needed to extinguish the fire, so a constant supply of water is needed. One of the biggest explosions of this type was in the year 2005, in Buncesfield near London. That was one of England's largest oil storage depots. In this fire fighting operation, firefighters used 417 litres of water per second. (8)

Furthermore,in fire fighting industry, a huge amount of water is used to extinguish fires. The automation of a water tank would be useful in this industry. One good example is a gravity water tank that supplies fire hydrants. In the eventuality of a fire, again, constant water supply is needed for the hydrants.

Another area where fluid level can be a problem is in the fuel and chemical industry (although for this project we have decided to focus mainly on water level in tanks, this example is worth mentioning for future upgrades). An overflow in storage tank containing oil or dangerous chemicals can be a threat and an eventual overflow means a possibly big financial loss.

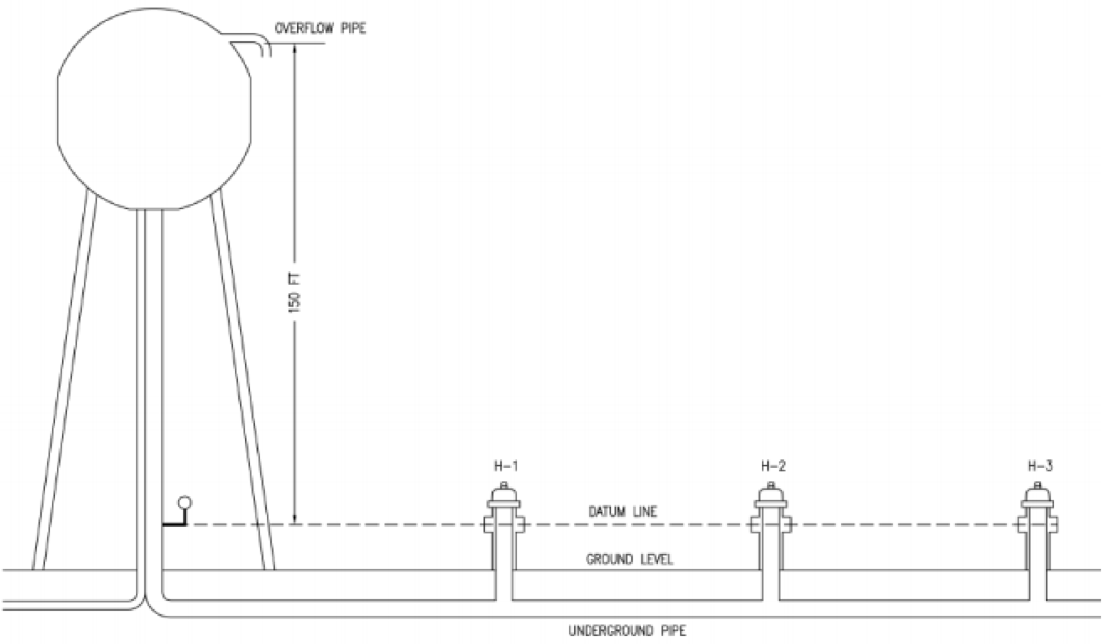

Figure 3- Elevated gravity tank supplying three fire hydrants (9)

'How' is it a problem?

1. Obstruction of the valves.
2. Depletion rate >> feeding rate.
3. Low levels.
4. Low Pressure.
5. Lack of maintenance (impurities, rust – see cathodic protection -).

'Why' is it a problem?

1. Low or very low flow of the main water source.

2. Fluctuating flow of the main water source.

As a set of specifications (based on a self-education principle) for this project, the solution should include:

- an understanding of how to implement and get a flow sensor to work
- an understanding of an ultrasonic sensor
- a demonstration that the group is able to take multiple sensor inputs into account before performing an action (performed via code)
- a demonstration that the solution is able to use hysteresis to keep the level between an error margin
- a demonstration that the solution is able to display different methods of measurement in real time, i.e. percentage, time and volume
- a demonstration that the group is able to program and understand the relevant mathematics needed to obtain the aforementioned results

Conclusion of problem analysis

Automation would bring a higher level of monitoring and control over the problem at hand: maintaining the water level in a tank or system of tanks, based on the hysteresis principle. It eliminates processes that would otherwise be done manually, with a lower level of precision, and that would require more manpower and higher costs over time. Having the capacity of normalizing the outflow of such systems allows a higher grade of comfort in the case of communities, a higher grade of security when applied to fire control systems and higher efficiency when used in agriculture and other industries.

Another important aspect is that the problem of a continuous supply of water cannot be solved completely. In cases where the feeding source of water has a dramatically lower flow than the outflow of the system, the only expected outcome of a solution would be to alter depletion time at a required out flow rate by effectively managing a buffer/reserve volume of water in correlation with the minimal feeding sources.

Definition of task

Automatic water tanks are already used in industries and for personal use, so basically where a constant supply of water is needed. The advantages of such a system are without any question of a great benefit because human effort is minimized and accuracy as well as error rate are drastically minimized, but the purpose of this project is not to focus on automation at an industrial level (although some research and calculations are made to have some insight into depletion rate, inflow rate and to know how will such a system work in the real world where any error means time and money loss) but to gain experience and insight into automation overall so the main focus is the prototype. The prototype will offer a good insight into automation, how the related parts are working, the theoretical knowledge needed to perform calculations and explain all the physical phenomena happening insight the actual functionality of the prototype (for example how the electrical pump uses any form of energy to perform work to move the fluid or the study of the linearity of water flow in a tank). The prototype has a major impact on the learning goals of this semester as calculations, simulations and diagrams will be made as well as the required theory covered.

The purpose of this project is to reach automation on a small scale and extrapolate the experience to how automation works at an industrial scale and in different industries. Inspecting that, gives an even deeper insight into how sensors work and in which conditions, because different industries will use different sensors to sense the level of liquid inside a tank.

The small scale automation will be made using two different types of sensors and three tanks; although at an industrial level the numbers of tanks and sensors may vary because different industries use different types of liquids or substances and need different precision in measuring the liquid level. The main focus is defining the functionality of such a system and the overall effects at an industrial scale as well as the impact of the parts over the environment and humans (if any).

The task will be to develop a small scale monitoring and control apparatus that will cover the general knowledge and skills needed to maintain water level or generate lower depletion rates related to water tanks.

Theoretical and experimental parts

How to calculate water outflow?

There are a couple of ways in which the outflow of water from a water tank can be calculated. One of them is the Hazel-Williams Equation. (10)

V=k*C*$R^{0.63}$*$S^{0.54}$ where:

v- Velocity of the water;

k- Conversion factor for unit system (k=0.849 for units of m/s and k=1.318 for units of feet/s);

C- Factor for relative roughness;

R- Hydraulic radius (R=$\frac{A}{P}$ where A is cross section area of flow and P is wetter perimeter);

S- Slope of the energy line (head loss divided by pipe length; S=$\frac{Hf}{L}$);

The Hazel-Williams Equation is used to determine the water outflow based on the pipes physical proprieties and the energy loss due to friction of the moving fluid through the pipe. It is also called “friction loss”. This equation can be used only for water, which must have a temperature between 4°- 25 ° Celsius.

Another method to determine the water outflow is by using Bernoulli’s Equation.

P+$\frac{1}{2}$ρV^2+ρgh=constant where,

p- Pressure (measured in Pascal);

ρ- Density (measured in kg/m^3);

V- Velocity (measured in m/s);

g- Gravitational acceleration (approximately 9, 81 m/s^2 $at\ sea\ level$);

h- Elevation of the water;

Bernoulli's principle

For this project, Bernoulli's principle will be used to calculate the velocity of the water that is exiting the tank. After calculating the velocity, the outflow rate and the time of depletion are relatively straightforward to calculate. (11)

Specifications of the tanks used for demonstration purposes:

-Maximum capacity (measured in litres) – 9

-Maximum Height (measured in centimetres) - 15

-Height 1 (H1- measured in centimetres) – 12, 5

-Height 2 (H2- measured in centimetres) - 2, 5

-Width (measured in centimetres) - 20

-Length (measured in centimetres) - 30

-Diameter of the orifice (measured in centimetres) – 1

The reason why there are two heights is the fact that one of them must be considered a reference point for the other. In this case, H2 will be considered the reference height for H1 (so the height from H2 to the maximum height could be calculated).

Demonstration of the formula used to determine the velocity

The starting point is the Bernoulli's equation considered at 2 different points (H2 and respectively at the maximum height).The reason why H2 is taken as a reference point is because the water level will exit the tank through an orifice at that height.

$P1+\frac{1}{2}*\rho*V1^2+\rho*g*H1=P2+\frac{1}{2}*\rho*V2^2+\rho*g*H2$ where,

P1 and P2- static pressures;

$\frac{1}{2}*\rho*V1^2$ and $\frac{1}{2}*\rho*V2^2$- kinematic pressures;

$\rho*g*H1$ and $\rho*g*H2$- dynamic pressures;

We consider H2=0 because it is considered the reference point from where any other height can be calculated; the initial velocity is V1=0 because initially the fluid is at rest. It is also known that the static pressures P1=P2=1atm (atmosphere) because the atmospheric pressure that affects the liquid is considered to be approximately 1 at sea level. Because the tank is a small one, only the atmospheric pressure will be taken into consideration.

Knowing the following, the equation becomes:

1+ $\frac{1}{2} * \rho * 0^2$+ ρ*g*H1=1+$\frac{1}{2}$*ρ$* V2^2$+ ρ*g*0;

ρ*g*h1=$\frac{1}{2}$*ρ$* V2^2$ (after subtracting 1 from each side of the equality).

After dividing each side of equality with ρ, the equation will become g*H1=$\frac{1}{2}V2^2$ => v=$\sqrt{2 * \mathrm{g} * \mathrm{H1}}$;

The final form of Bernoulli's equation for the given situation is v=$\sqrt{2 * \mathrm{g} * \mathrm{H1}}$, also known as Torricelli's equation, which is a special case for Bernoulli's equation.

It can be seen from Torricelli's equation that the velocity of the fluid is dependent on the current height. If the height decreases, so does the velocity and vice versa. (12)

Theoretical calculation of the depletion time of the water in the water tank using Torricelli's equation

For the theoretical part, Torricelli's equation will be used: v=$\sqrt{2 * \mathrm{g} * \mathrm{H1}}$

Firstly, it is necessary to calculate H1 by subtracting H2 from the maximum height of the tank

H1=Hmax-H2=15-2.5=12.5 cm (0.125m);

The velocity becomes v=$\sqrt{2 * 9{,}81 * 0.125}$=1, 56 m/s.

The equation for the outflow through the orifice is Q=v*A where A is the area of a circle.

Knowing the velocity, the outflow will become:

Q=v*π*r^2=1, 56*3, 14159*0,005*0.005=0, 00012 m^3/s=0, 12 l/s.

The formula for time until depletion is T=V/Q (T=$\frac{9}{0{,}12}$=75 s).

Experimental data and demonstration of the Bernoulli's Principle

In the attempt to make a more technical project, experiments have been done in order to demonstrate Bernoulli's Principle in water tanks and to determine the depletion time of the tank using a stopwatch. Although only four experimental data has been collected, Bernoulli's principle and the dependency of the velocity on the current height have been demonstrated successfully.

The fact that only four experiments have been done make the average time of the depletion of the water in the tank not very accurate. More experiments should have been done in order to obtain a better average time in which the tank will completely deplete.

During the experiments, it was seen that the pipes affect the velocity of the water which led to a longer depletion time. This is why there were made four experiments using the pipes and the water flow sensor and four experiments in which the water was simply flowing from the tank. In the experiments where the water was simply released from the tank, the velocity of the water could not be calculated as the flow sensor was not used. Because of the big volume of data just two of each were presented in the report and the other four were placed in the annex.

Test 1	Volume	Time
15	9	4
14	8.4	4.9
13	7.8	4.9
12	7.2	5.5
11	6.6	5
10	6	5.9
9	5.4	6.8
8	4.8	7.4
7	4.2	7.3
6	3.6	12
5	3	12.5
4	2.4	29.8

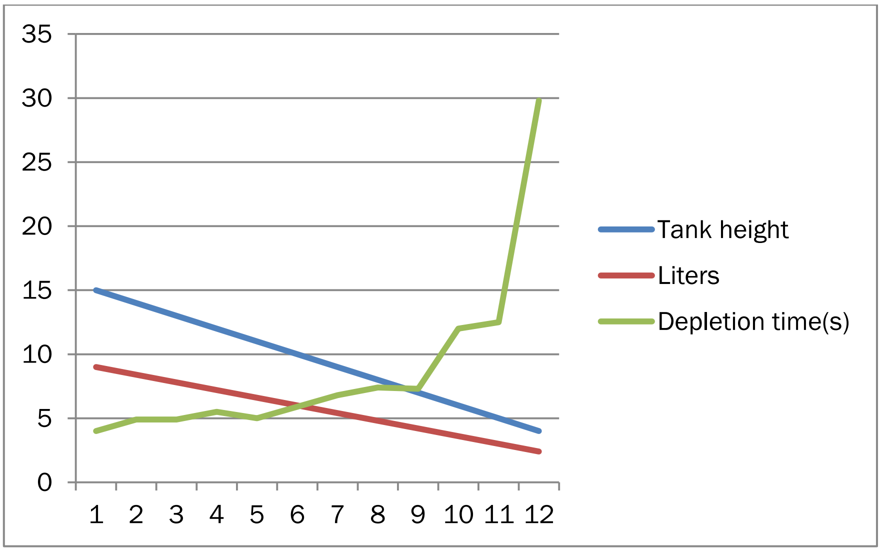

Figure 4- Graphic corresponding to Test 1(without pipes and sensors)

Test 2	Volume	Time
15	9	4
14	8.4	5.2
13	7.8	4.8
12	7.2	5.3
11	6.6	4.6
10	6	5.8
9	5.4	7.1
8	4.8	6.7
7	4.2	8.4
6	3.6	10.2
5	3	13.3
4	2.4	33.3

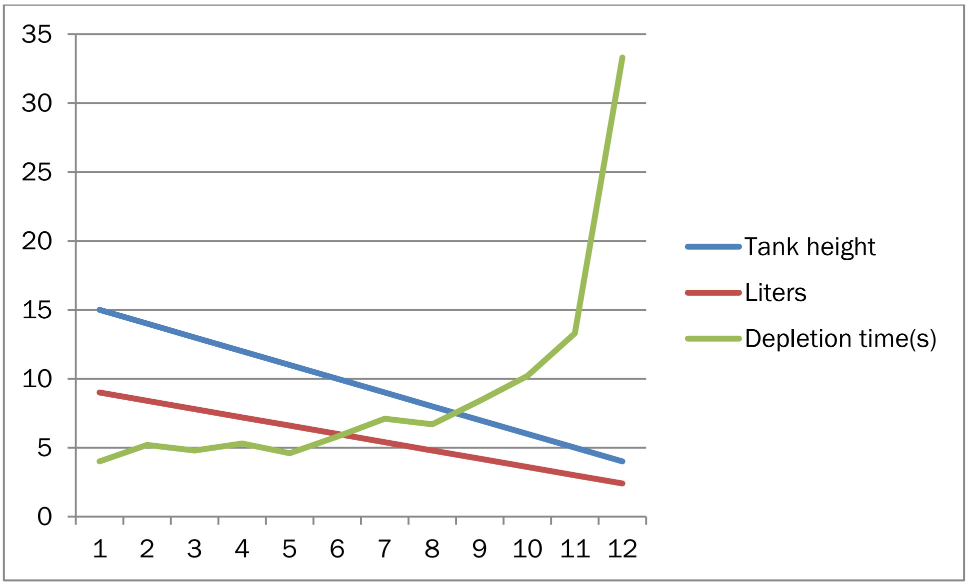

Figure 5- Graphic corresponding to Test 2 (without pipes and sensors)

Test 3	Volume	Velocity	Time
15	9	29	62
14	8.4	28	84
13	7.8	28	84
12	7.2	28	76
11	6.6	28	78
10	6	27	80.8
9	5.4	26.5	87.5
8	4.8	26	78.4
7	4.2	25	84.6
6	3.6	25	90
5	3	24	80
4	2.4	23	90

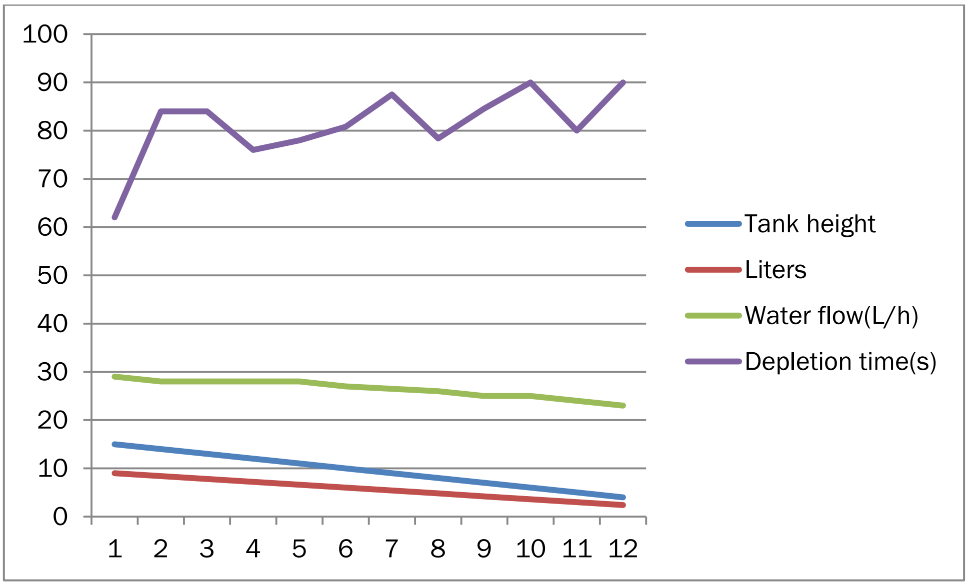

Figure 6- Graphic corresponding to Test 3(with pipes and sensors)

Test 4	Volume	Velocity	Time
15	9	26	70
14	8.4	25.5	77
13	7.8	25	81
12	7.2	25.5	81
11	6.6	24.5	83
10	6	24	70
9	5.4	23	84.4
8	4.8	22.5	87.8
7	4.2	22	81
6	3.6	22	88.5
5	3	22	89
4	2.4	21	91

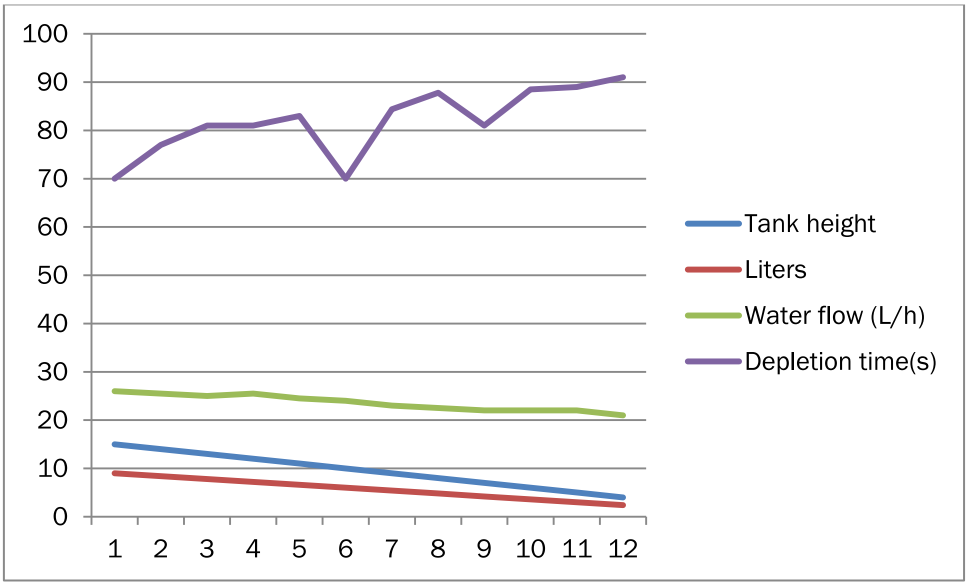

Figure 7- Graphic corresponding to Test 4(with pipes and sensors)

The first two tables and graphics illustrate the values registered in the experiments where the pipes and water flow sensors were not used. The other two tables and graphics illustrate the values registered in the experiments where the water was flowing through the pipes and water flow sensor.

In all of the experiments, volume was measured in m^3, the velocity in $\frac{m}{s}$ and the time in seconds. (The International System of Units was permanently used for all values in this project).

Comparison between the values obtains through theoretical principles and the ones obtained through experimental data.

The theoretical calculations are really close to the experimental data (in the theoretical part, the depletion time was calculated to be 75 s whereas in the experimental data the average was 75.87 s). Although only eight experiments were made in order to measure the time until depletion, the results are very close one to another showing that the theory was applied accurately to check the experimental data. The difference of almost a second between the theoretical calculations and experimental data can be a result of a human measuring error in both time and length.

In the next projects, more emphasis must be made on the testing of the prototype in order to correlate the theoretical principles with the practical values in order to gain a better understand of the relationship between equations and physical phenomena.

Solution

Ultrasonic sensor:

One of the sensors that were used for this prototype is an ultrasonic sensor (hc-sr04 model). With this sensors the volume of water from the tank can be calculated by using the well know formula surface multiplied by height. (13)

The sensor has a range from 2 cm to 400 cm that will work for the prototype and demonstrations purposes. For a bigger tank the same principle can be used but with a larger sensor that can measure the needed distance.

The way that the ultrasonic sensor is working is the following:

1) To start the measurement, the sensors need to receive a high pulse (5v) for at least 10µS which will start the module.

2) After the sensor it's initiated it will send 8 cycle of ultrasonic burst at 40 kHz and wait for the reflected ultrasonic burst.

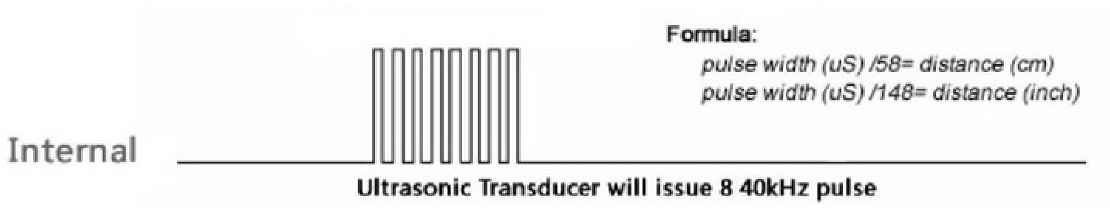

Figure 8 - A visual representation of the 8 cycle of ultrasonic burst (13)

3) When the receiver detects the ultrasonic burst will set the Echo pin on high (5v) and delay it for a period (width) which is proportion to the distance.

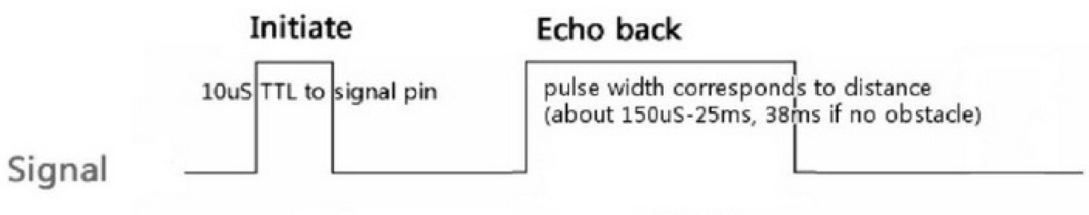

Figure 9- A visual representation of the received signal: the initial signal and the echo (13)

The distance is calculated by a simple formula: the distance = level time (Time) * velocity (340M/S) / 2; where the Time = Width of Echo pulse in µS (micro seconds).

This ultrasonic sensor is the main source of measurement for the volume of the tank. The other sensor used in this prototype is a water flow sensor, one that is used to check the inflow and outflow of the liquid from the tank.

Water flow sensor:

For the prototype two water flow sensors are used, one for the inflow and one for the outflow. The difference between this two will show the depletion rate or the repletion rate of the tank.

The sensor is using a Hall Effect sensor to measure the output pulse signal. The simplest way to explain the Hall Effect that we used in this prototype is thinking of a circle that has a magnet on the edge and a sensor. Every time when the magnet passes in front of the Hall Effect sensor a current appears that acts like a signal. This signal represents a full revolution of the circle and with this information it is easy to calculate the number of revolution. The rotor inside the water flow sensor has a fixed volume. So the amount of water can be calculated by the number of revolutions multiply by the volume of the rotor. (14)

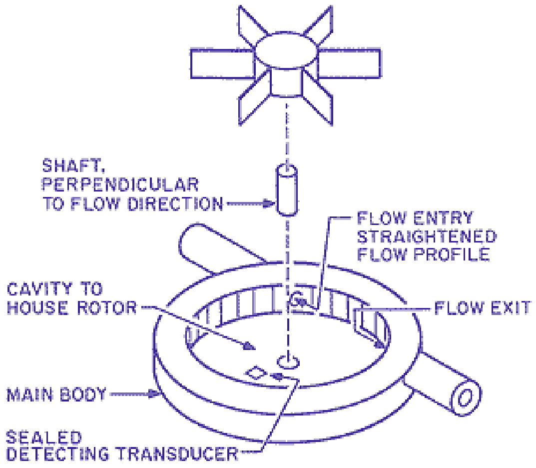

Figure 10- A visual representation of the rotor inside the water flow sensor (15)

In the image above it is visible how the sensor works. The water is going through the flow entry, spinning the blades of the rotor and the sensor is measuring how many revolutions the rotor is doing in a certain period of time (for the prototype the time used for measuring is one second).

Relay:

A relay is a switch that separates the main circuit from the electrical signal needed for switching the main one on/off. This type of switch is useful when a high voltage circuit needs to be controlled with a low voltage input.

To control the relay, the power signal that is sent to the coil is activating the electromagnet that attracts the armature witch acts like as a switch in the main line. So when the electromagnet is energized, the armature is making a connection and the main load is a close circuit. When the electromagnet is not energized, the spring is keeping the circuit opened. There are two types of relay: one that is normally open (NO) and one that is normally close (NC). (16)

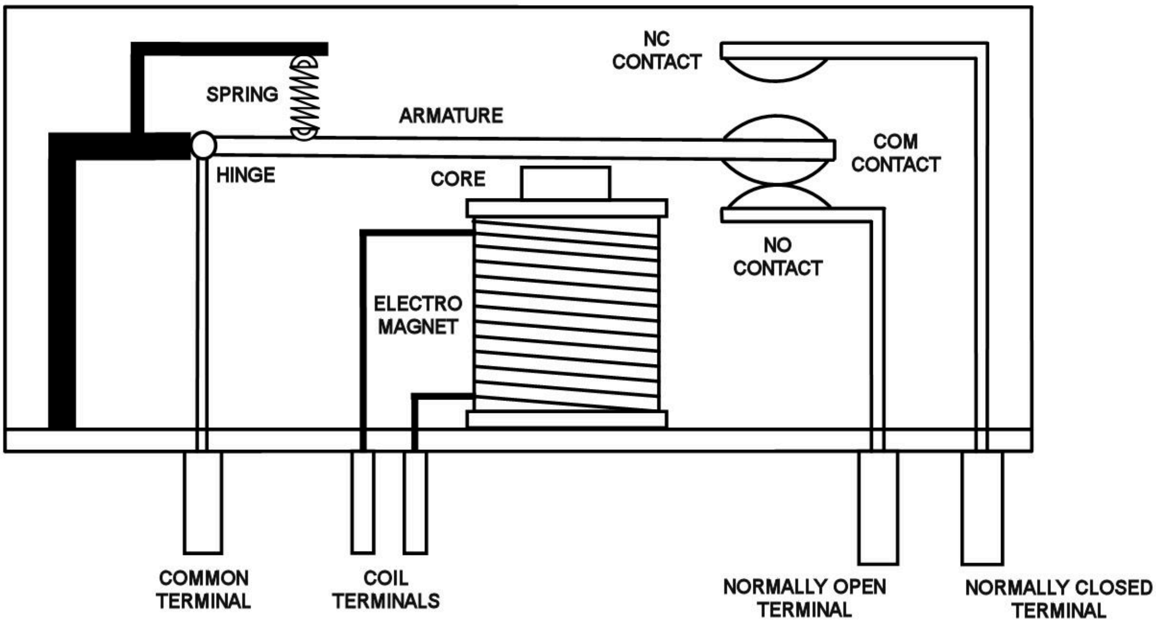

Figure 11- Relay (17)

Magnetic valve:

For controlling the inflow and outflow of the water, two direct-acting solenoid (magnetic) valves are used. The difference between a normal valve and the magnetic one is the way that the valve is controlled on/off. In the normal one, a physical interaction is necessary with the valve (somebody needs to turn it on or off). The magnetic one is doing the same thing but is using an electric signal so that the human interaction is eliminated. This can be a good thing especially when the valve is not in a accessible place. (18)

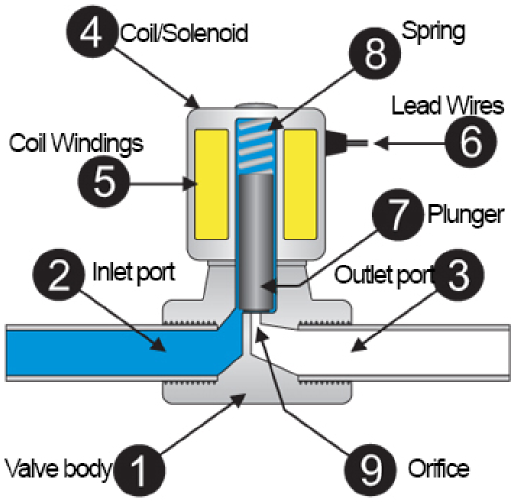

Figure 12- A diagram that shows the inside of the solenoid valve (18)

A solenoid valve has the default state close. The spring is pushing the plunger down, blocking the orifice that is holding the water. To turn the valve on, an electric current is necessary. This current is creating an electromagnetic field in the coil and lifts up the plunger to let the water flow.

LCD Shield for Arduino:

For the information that is collected by the sensors and processed by Arduino, the prototype needs to show this information in an easy and intuitive way. Here the LCD screen is coming in use. The screen consists of a 1602 white character blue backlight LCD. The keypad has 5 keys: up, down, left, right and select. The keys values are read through a 5 stage voltage divider. Using this voltage divider digital IO pins are saved because the divider is using just an analog pin. (19)

Figure 13- Picture with the LCD Shield (20)

Arduino Uno:

The brain of this prototype is the Arduino Uno microcontroller board based on the ATmega328. The board has 14 digital input/output and 6 analog inputs that are enough for this prototype. Arduino has also pins for power and grounding, this is making the assembling very easy because the parts can use the power directly from the board with no need for an external power source. The board has 32KB of flash memory, 2KB of SRAM (Static random-access memory) and 1KB of EEPROM (Electrically Erasable Programmable Read-Only Memory).The flash memory used for storing the programmable code is more than enough for the purposes of this prototype. Arduino is very easy to use and has a user-friendly interface for programing the code. The board has a very big community for coding and schematics behind. This makes it very easy to find examples, codes, instruction and find ways to solve the problems that one can meet. (21)

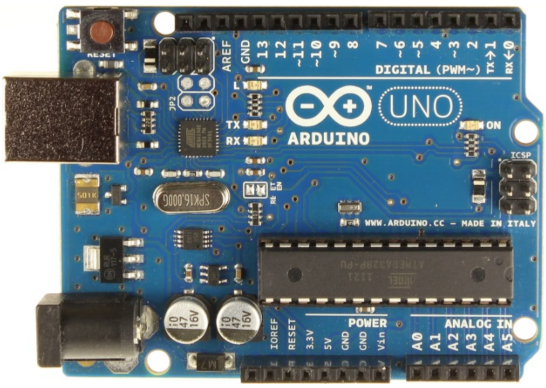

Figure 14- Arduino Uno microcontroller (21)

MOSFET Transistor:

A MOSFET (metal–oxide–semiconductor field-effect transistor) transistor is a switch that can be turn on/off by an electric signal. The way that the transistor works is a very simple one.

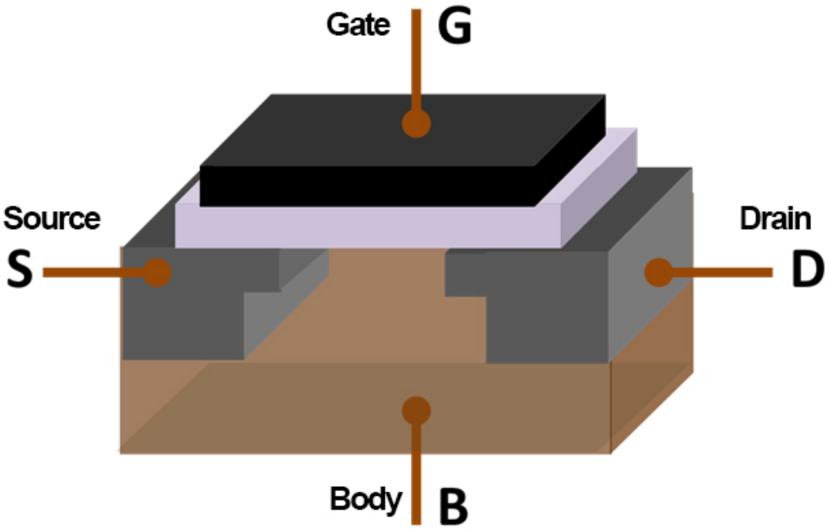

Figure1 2- A visual representation of a MOSFET transistor (22)

In the figure above it is visible the construction of the transistor. It is easy to think at the MOSFET as a variable resistor where the Drain-Source resistance is a function of the voltage difference on the Gate-Source pins. If between the Gate-Source is no potential difference, then the Drain-Source resistance is very high and can be considered an open switch, so no current is going through. If is a large potential difference between Gate-Source then the Drain-Source resistance is very low, so the current can flow through. (23)

Health and safety issues both at an industrial level and prototype level.

The parts that make the actual system are basically two sensors (One is used as the main liquid level sensor and another one is used to determine the water flow), one electric pump, two electric valves that are opening and closing if the water level is not in the desired level range and a microcontroller that is controlling the electric valves based on the input given by the sensors.

Ultrasonic sensors are used in a huge range of applications from the automotive industry (used for parking systems) to most automated factories that use this kind of sensors to know exactly the distance from an object to another. Ultrasonic sensors use high frequency sound waves (sound waves that are at a higher frequency than are greater that the upper limit of human hearing, which is 20 kHz or 20,000 Hz). Ultrasounds have no impact on human health when the exposure is under a certain limit, such as the use for diagnostic purposes in medicine, but long exposure to ultrasounds can cause “permanent damage to biological tissues, including teratogenic effects, through heating, acoustic cavitation or radiation force”. (24) Fortunately, long human exposure at ultrasounds is not the case in a storage water tank, so the impact on humans is none or minimal.

The electric pump is using a power source and its main application is to provide flow of water (be it inflow or outflow) in or from a water tank. The basic functionality of the pump is pretty straight forward. It uses electric power (or any kind of energy) to exert mechanical work on the fluid using the force of the water over the distance it covers while the force is applied. The major impact of electric pumps is not on humans, but fish. According to The Seattle Times, 200,000 young salmon and steelhead were killed when a pump failed at the Lower Elwha Klallam fish hatchery. (25)

Arduino is a single-board microcontroller produced by the Italian company SmartProjects. This microcontroller is widely used by DIY adepts because it is very easy to use and the easiness and range which one can find related accessories is astonishing. There are no reports of any accidents using Arduino so that makes it a safe microcontroller to use in this project. At an industrial level, the programming and processing can be made by any computer that can process that amount of information.

The most dangerous components that were included in the prototype are the electrectic valves. These valves are dangerous especially for the prototype because they require a power supply of 220V. Without their proper handling or due to a malfunction, one can experience a serious electric shock. In certain conditions even a small voltage is fatal (If one is bare foot, has his feet in water and so on).

Although most of the components that were used to build the prototype are considered harmless for humans, no electrical equipment should be used without proper supervision.

Construction:

The prototype had two models of construction and code. In the picture below is presented the first prototype. This prototype includes: Arduino Uno, ultrasonic sensor, water flow sensors, valves, transistors and the LCD Shield for Arduino. Because not every part could be found in the program used for creating the model diagram of the circuit, the led represent the transistor valve group because the transistor is turned on/off exactly like a LED, by receiving power from an Arduino pin. Another part that was not included in the program was the water flow sensor, so for visualization purposes a transistor was used because exactly like the sensor, it has 3 pins. Even if some parts are not represented in the diagram, the wiring is the same and the colour for the wires is respected.

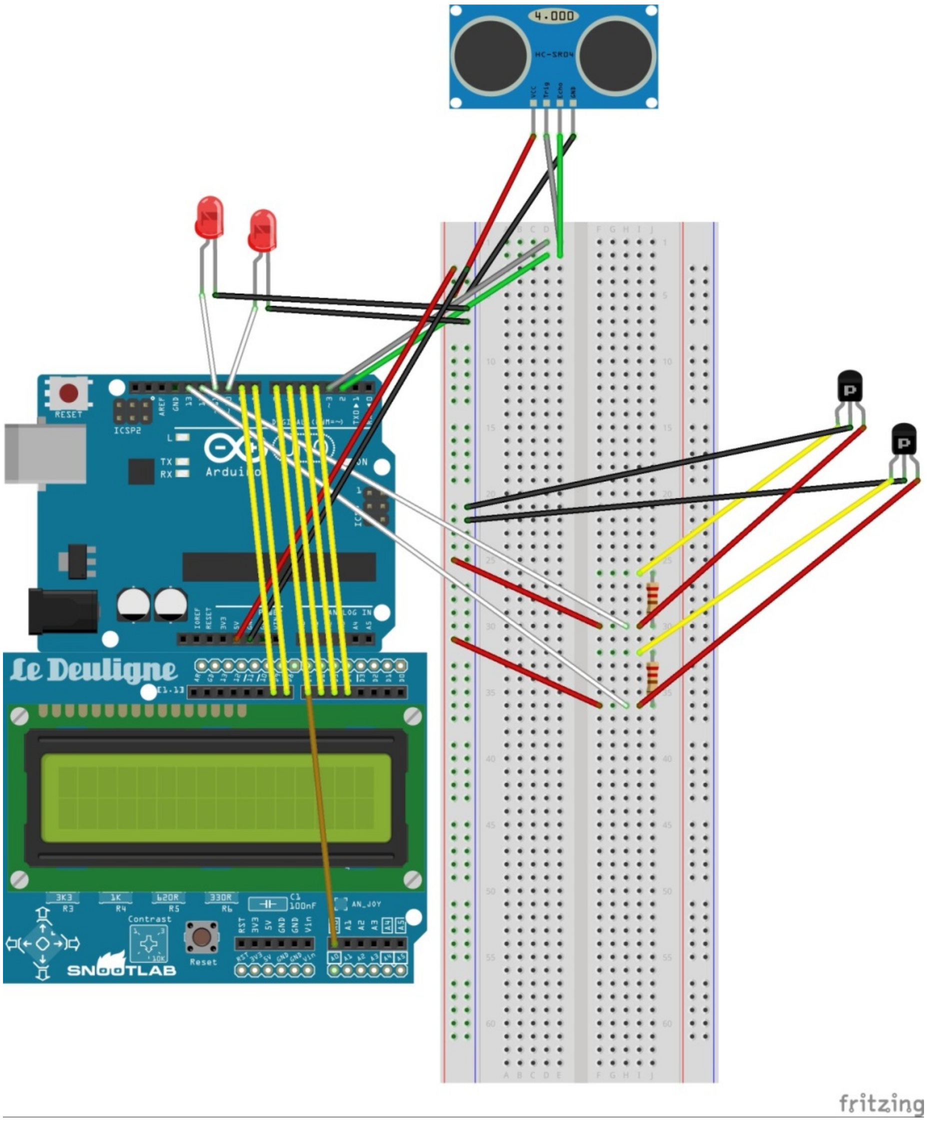

Figure 13- PCB

The first step for building the prototype was the code for the menu in the LCD screen.The information received from the sensors will have a nice representation. The first column of the menu is showing the “Total Volume” of the tank measured in litres, percentage, and percentage bar. There are 3 ways to see the total volume of water so people can choose what they feel is easier and intuitive to use for them. All of them have the same input from the sensors, just the code for interface is different. The second column is used to see the “Input/Output” values in 3 simple ways. On the first row there is the absolute value, the value obtained from the difference between output and input. The second row shows the input value and the third one the output. On the third column the depletion time of the tank is shown. On the last column the “Valve control” options are shown. Here is also possible to control the output valve on/off and the one for input respectively.

After the LCD Shield, the ultrasonic sensor was connected to the Arduino and the code for it has been written. The pins for the valves were set and connected to the control buttons on the LCD shield. The last parts necessary for the prototype were the water flow sensors. This last part had some problems with the code. The results obtain at the first attempt were bad because the formula for the flow was wrong. After this was fixed, another problem occurred because in the beginning just one water flow sensor was used. The second one was not working when the prototype was put together because a certain pin from the Arduino was needed for the sensor to work. This problem was fixed by trying a completely new code for the water flow sensor so that any pin can be used from the Arduino board.

After solving this problem another big problem occured. The water flow sensor needs one second delay to obtain the information, so in the code was necessary to put this delay. The Arduino code is split into two parts, one that is running just the ones where everything is declared and initialized; and the other one which is a loop that is running while the Arduino is powered up. Because the LCD shield and the sensor where in the loop part, the second delay needed for the sensor to read was also applied to the screen and buttons. This delay was making the screen impossible to read and was necessary to hold one button for 1.5-2 seconds until the information will be received by the Arduino.

At this point almost everything was working separately with no problem, but when the sensor and the screen where put in the same Arduino, there was a big interface problem.This way the second model of the prototype appeared.

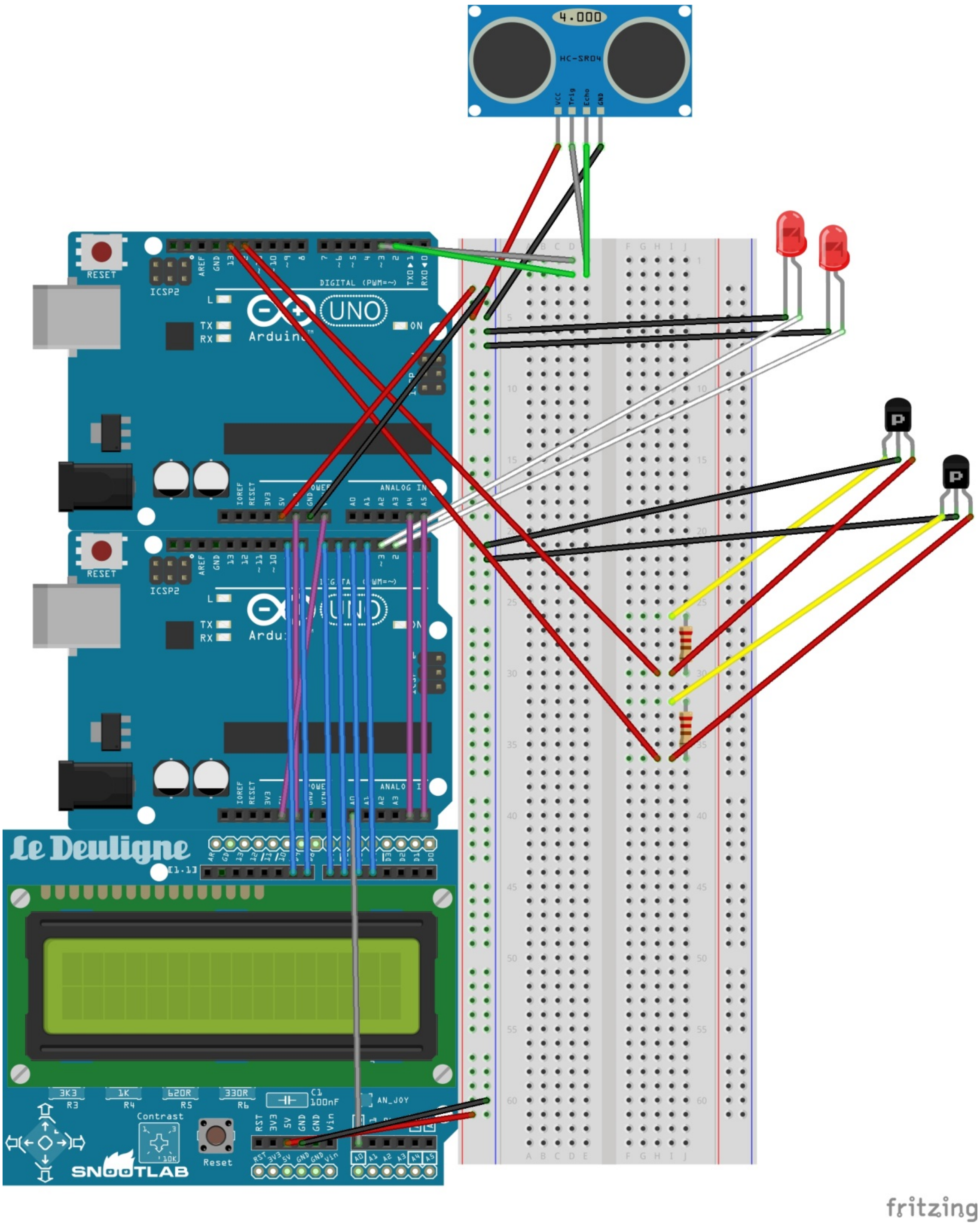

Figure 17- PCB

Because the problem was the location of both the sensor and the screen on the same Arduino, the simplest solution was to use two Arduino. One that will act as “the brain” and will read everything and make the calculations (where all the sensors will be placed) and the second Arduino just for the interface.

In this way a direct connection through two analog pins was needed between the Arduino boards for communication. The code was divided in two parts, one for “the brain” and the other one for the screen.

After fixing this problem the prototype was working and just some small adjustments were necessary in the code when it was implemented in the small scale tank.

Specifications of the prototype:

The prototype is connected to power by USB which is connected to a computer, but can also work connected to 5V DC from an external source. Also the water flow sensors, the LCD Shield and the ultrasonic sensor are connected to the Arduino board so there is no need for an external power supply. For the magnetic valves an external 220V external power source is necessary for switching them on/off, but the electrical signal that is activating the relay is also connected to the Arduino’s power and ground. The pump needs also 220v for powering it up. The maximum volume that the tank can hold for the ultrasonic to be able to work is 9L and the minimum value is 1.2L. The minimum value is not 0 because the output hole is not exactly on the bottom of the tank and under 1.2 L no water will flow out.

Conclusion to the solution part

The prototype for this project is much more complex than the one for the P1 because it is meant to create automation in a water tank (its purpose is to be used in industries and less for domestic use).

Although for this prototype were used only some types of sensors, there are many ways to go around. The reason why these specific sensors have been used is because of convenience.

The construction of the prototype was not easy as the individual parts were rather hard to find. Beside the difficulty of finding some parts, some technical problems occurred as it was needed some relays to control the electrical valves with the Arduino. The first intention was to use transistors, more precisely a MOSFET so we could include in the project some of the theoretical and practical knowledge our group have acquired in the Electrical Engineering course. In the end a relay was used, but an external power source was needed in order to supply 220V to the electrical valves and so that the relay could be controlled by the Arduino.

During this period while the prototype had to be made, other fields of study were studied in order to obtain a better understanding about the velocity and water flow (such fields of study are fluid dynamics) which led to a broader learning goals rather than strict ones(the ones mentioned in the curriculum).

Considerations

Since the project is to give general insight in the working principles involved, several phenomena, or special properties of fluids have not been taken into consideration. Compressibility and viscosity have not been taken into consideration, nor the different behaviour of laminar or non-laminar flows, of subsonic, transonic, supersonic or hypersonic flows or the compressibility of water in gas state (vapours). Also Orifice Discharge Coefficient (ratio of the actual discharge to the theoretical discharge through the orifice) has been evaluated at 1 since the velocity of the fluid is relatively small in module, velocities at which the transfer of fluids through the orifice makes no impact in the situation presented in the above project.

Since the pressure difference at the bottom of the tank from the one at the top of the tank when the respective recipient is full is very small, it has been considered negligible because the tank used has relatively small measurements, (0.02 m × 0.03 m × 0.018 m).

All these variables have to be factored in when the working principles have to be applied to the real world, and some differences from the working principles can be encountered.

Correlation of data

Generally, the data obtained through theoretical means have not been completely convergent with the data obtained through experimental means. However, the number of tests executed solely on the purpose of data collection has been limited thus reducing the statistical accuracy. Most of the tests have been done independently for different parts before they were put together, either to test parts of the programming or to simply test functionality and working principles of those parts. As mentioned above, several other factors have not been taken into consideration, adding further more to the potential for different results between the theoretical and experimental data.

However, even with the slight differences between the two types of data, a parallel trend both in the data as well as in the results can be observed, prompting the conclusion that if all the factors would have been taken into consideration, the results would have been coherent and very reliable.

For future reference, an emphasis should be put on the collection of experimental and theoretical data, comparison made with virtual simulations to ensure convergent results.

A very important part of the work has been the programming. Whilst the prototype has been relatively easy to construct (with difficulties encountered in executing the plumbing part connecting sensors, valves and tanks due to improvising solutions for various gauges and standards, improvising solutions for water-proofing the whole prototype), the complexity of the programming has been the core of the project. The challenge to offer a wide range of information about the status of the system, coupled with the controlling valves and sensors, and converting a linear signal offered by the water flow and continuous level drop in the tank into digital signals was our main focus, task in which the project has definitely succeeded.

Index

Elevated water tank – a water tank supported by a steel or concrete tower that does not form part of the storage volume.

Standpipe water tank – a water tank that is located on the ground surface and has a greater height than diameter.

Reservoir (Ground) water tank– a water tank that is located on the ground where the width/diameter is greater than the height.

In-Ground (Buried) water tank – a water storage tank that is partially or totally below the nominal surface of the ground.

HGL - hydraulic grade line.

Overflow – when the water level exceeds the maximum level that the tank can support.

Volume - the space that a certain liquid or substance occupies between a predefined bounded surface .In the International System of units, volume is measured in m^3*(cubic meters).*

Pressure- pressure is defined by the relationship $\frac{\mathrm{F}}{\mathrm{A}}$ *where F represents the force (In the International System of Units it is measured in Newton) and A is the area over which the force is distributed (in the International System of Units it is measured in Pascal).*

g (gravitational acceleration)- is approximately 9,81 m/s^2*, the value being considered at the sea level.*

ρ- is called density. Density is defined by the formula $\frac{m}{V}$ *where m is the mass and V is the volume. In the International System of Units it is measured in* kg/m^3*.*

Bernoulli's principle or the Bernoulli Effect-the principle of this effect is that the pressure of a liquid is dropping down as the velocity of that liquids flow is increasing.

UHP- Ultra High-Pressure.

Teratogenic Effect- the long exposure to ultrasounds can affect the fetus (in case of a pregnant woman) which may lead to mental retardation and growth deficiency.

*Work- work is a physical measure and it is defined by the relationship F*d where F is the force and d is the distance where the force is applied. In the International System Of Units, work is measured in Joule (J) and the usual symbol for work is W.*

DIY- Do It Yourself.

Hall Effect- This effect consists of the apparition of an electric field and a potential difference in a semiconductor or metal when electrons flow through it and a magnetic field is introduced perpendicular to the electric field.

Solenoid- a coil that is shaped like a helix. It was first invented by Andre-Marie Ampere. It is used to produce a constant magnetic field when it is wrapped around a metallic core.

LCD- Liquid Crystal Display.

IO- Input/Output.

SRAM- Static Random-Access Memory.

EEPROM- Electrically Erasable Programmable Read-Only Memory.

Transistor- is a device made from 2 types of semiconductors (n-type and p-type).Its main function is to amplify electrical signals and switch between these signals as well as electrical power.

LED-Light-emitting diode.

PCB-Printed Circuit Board.

Gauge-"an instrument that measures and gives a visual display of the amount, level, or contents of something:" http://www.oxforddictionaries.com/definition/english/gauge

Debit-the volume of water that flow through the cross-section per time unit.

Sensor- is a type of transducer (converts a form of energy from another). Converts an analog signal into a digital one.

Hydraulic radius- is used to calculate the flow a liquid through a noncircular pipe.

Atmosphere (atm)- is a measure unit for pressure. At sea level is approximately 1,03 kg.

Air pressure- is the force exerted by the weight of air.

Relay-a type of transistor.

Ultrasound-a sound with a higher frequency than the upper limit of the human hearing.

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Annexes

Code:

```
#include <PinChangeInt.h>  //Library for the pins used for the water flow sensors

#include <Wire.h>   // Library used for communication between  the arduinos

#define PIN1 2   // Declare  the pin number 2 for water flow sensor

#define PIN2 3  // Declare  the pin number 3 for water flow sensor

const int trigPin = 5; // Set up pin number 5 for  triggering  the ultrasonic sensor

const int echoPin = 4;  // Set up pin number 4 to receiving information from   the ultrasonic sensor

long duration,cm;

uint8_t latest_interrupted_pin;

uint8_t interrupt_count[20]={0};   // An array that can make any pin on the board able to receive
information from the water flow sensor

 uint8_t count;  //define the count variable byte type

  uint8_t count1;   //define the count1 variable byte type

void quicfunc() {

  latest_interrupted_pin=PCintPort::arduinoPin;

  interrupt_count[latest_interrupted_pin]++;

}; // function used to calculate the peaks in the water flow signal.


void setup()

{

  pinMode(PIN1, INPUT); // PIN1 set up to be used like an input pin

 digitalWrite(PIN1, HIGH); //activating the pin

  PCintPort::attachInterrupt(PIN1, &quicfunc, FALLING);  //connect the pin to the function used for
calculating the peaks.

  pinMode(PIN2, INPUT); // PIN2 set up to be used like an input pin

digitalWrite(PIN2, HIGH); //activating the pin

  PCintPort::attachInterrupt(PIN2, &quicfunc, FALLING); //connect the pin to the function used for
calculating the peaks.

  Wire.begin(); //  Starting up the communication between the arduinos
```

```
}
void loop() {
   transmision(); // sending the information to the other arduino;
  delay(1000); // 1 second delay necessary for the sensors to read in informations
  if (interrupt_count[3] != 0) // checking if pin number 3 has input values
{
      count=interrupt_count[3];  //  saving the value in a variable
      interrupt_count[3]=0;  // resetting the value after read
  }
else
  {count=0;}
if(interrupt_count[2] != 0) // checking if pin number 2 has input values
{
      count1=interrupt_count[2]; //  saving the value in a variable
      interrupt_count[2]=0; // resetting the value after read
  }
else
  {count1=0;}
     // The sensor is triggered by a HIGH pulse of 10 or more microseconds.
  // Give a short LOW pulse beforehand to ensure a clean HIGH pulse:
  pinMode(trigPin, OUTPUT);
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  // Read the signal from the sensor: a HIGH pulse whose
  // duration is the time (in microseconds) from the sending
  pinMode(echoPin, INPUT);
  duration = pulseIn(echoPin, HIGH);
  // convert the time into a distance
  cm = microsecondsToCentimeters(duration);// using the function convert the time in centimetres
}
void transmision()
```

```
{Wire.beginTransmission(4); // transmit to device analog pin number 4
  Wire.write(count1);    // sends water flow value
  Wire.write(count);   //sends the second water flow value
  Wire.write(cm);  //sends the distance
  Wire.endTransmission();    // stop transmitting
}
long microsecondsToCentimeters(long microseconds)
{
  // The speed of sound is 340 m/s or 29 microseconds per centimeter.
  // The ping travels out and back, so to find the distance of the
  // object we take half of the distance travelled.
  return microseconds / 29 / 2;
}
```

```
#include <Wire.h> //library for arduino communication
#include <LiquidCrystal.h>  //library for the LCD shield
LiquidCrystal lcd(8, 9, 4, 5, 6, 7); // select the pins used on the LCD panel
int valve1 =2;
int  valce2 =3;
int x=0,y=0, z=0, i=1,j=1,kIN=1,kOUT=1, lcd_key   = 0, adc_key_in  = 0;
float tv=0,prc=0,dt;
int calc, calc1, absv;
#define btnRIGHT  0
#define btnUP     1
#define btnDOWN   2
#define btnLEFT   3
#define btnSELECT 4
```

```
#define btnNONE   5
void setup()
{
  Wire.begin(4);               // setting upp the connection with the other arduino
  Wire.onReceive(receiveEvent); // register event
   lcd.begin(16, 2);            // start the library
  pinMode(valve1, OUTPUT);
 pinMode(valve2, OUTPUT);
}

void loop()
{
calc=(x * 60 / 98);// calculating the water flow(L/h)
calc1=(y * 60 / 98); calculating the water flow(L/h)

absv=calc-calc1;
dt=tv/absv;
tv=(17-z)*0.6;
prc=(tv/8.4)*100;
if(prc>=100) // stopping  the input flow if the tank is full
kIN=0;
else
kIN=1;
if(prc<=0) // stopping  theout pu flow if the tank is empty
kOUT=0;
else
kOUT=1;
lcd_key = read_LCD_buttons();  // read the buttons

  switch (lcd_key)              // depending on which button was pushed, we perform an action
 {
   case btnRIGHT:
     {if(i==4)
     {i=1;}
```

```
 else
 {i++;}
 j=1;
 break;
 }
case btnLEFT:
 {if(i==1)
 {i=4;}
 else
 {i--;}
 j=1;
 break;
 }
case btnUP:
 {if(i==1)
 {
  if(j==1)
 {j=3;}
 else
 {j--;}
 }
 else
 if(i==2)
 {
  if(j==1)
 {j=3;}
 else
 {j--;}
 }
 else
 if(i==3)
 j=1;
 else
 if(i==4){
```

```
 {if(j==1)
 {j=2;}
 else
 {j--;}
 }
 }
 break;
 }
case btnDOWN:
 {if(i==1)
 {
  if(j==3)
 {j=1;}
 else
 {j++;}
 }
 else
 if(i==2)
 {
  if(j==3)
 {j=1;}
 else
 {j++;}
 }
 else
 if(i==3)
 j=1;
 else
 if(i==4){
 {if(j==2)
 {j=1;}
 else
 {j++;}
```

```
    }
    }
    break;
    }
  case btnSELECT:
    {if(i==4)
    { if(j==1)
      { if(kIN==1)
    kIN=0;
    else
    kIN=1;
  }
    else
    if(j==2)
    if(kOUT==1)
    kOUT=0;
    else
    kOUT=1;
  }
    break;
    }
    case btnNONE:
    {
    break;
    }
 }// for every button a condition it's placed developing a menu
 if(i==1&&j==1)
{lcd.clear();
 lcd.setCursor(2,0);
lcd.print("Total Volume");
lcd.setCursor(6,1);
lcd.print(tv);
}
else
```

```
if(i==1&&j==2)
{lcd.clear();
lcd.setCursor(2,0);
lcd.print("Total Volume");
lcd.setCursor(6,1);
lcd.print(prc);
lcd.print("%");
}
else
if(i==1&&j==3)
{lcd.clear();
lcd.setCursor(2,0);
lcd.print("Total Volume");
lcd.setCursor(1,1);
for(int i=1;i<=19-z;i++)
lcd.print("#");
}

if(i==2&&j==1)
{lcd.clear();
 lcd.setCursor(2,0);
lcd.print("Input/Output");
lcd.setCursor(0,1);
lcd.print("Absolut:");
lcd.print(absv);
}
else
if(i==2&&j==2)
{lcd.clear();
lcd.setCursor(2,0);
lcd.print("Input/Output");
lcd.setCursor(0,1);
lcd.print  ("Input:");
lcd.print(calc);
```

```
}
else
if(i==2&&j==3)
{lcd.clear();
lcd.setCursor(2,0);
lcd.print("Input/Output");
lcd.setCursor(0,1);
lcd.print("Output:");
lcd.print(calc1);
}
else
if(i==2&&j==3)
{lcd.clear();
lcd.setCursor(2,0);
lcd.print("Input/Output");
lcd.setCursor(4,1);
lcd.print("output value");
}
else
if(i==3&&j==1)
{lcd.clear();
lcd.setCursor(1,0);
lcd.print("Depletion Time");
lcd.setCursor(4,1);
if(absv==0)
{lcd.print("No flow");}
else
{lcd.print(dt);}
}
else
if(i==4&&j==1)
{lcd.clear();
lcd.setCursor(1,0);
lcd.print("Valve Control");
```

```
lcd.setCursor(0,1);
lcd.print("Input Status");
if(kIN==0)
{lcd.setCursor(12,1);
lcd.print(":OFF");}
else
{lcd.setCursor(12,1);
lcd.print(":ON");}
}
else
if(i==4&&j==2)
{lcd.clear();
lcd.setCursor(1,0);
lcd.print("Valve Control");
lcd.setCursor(0,1);
lcd.print("Output Status");
if(kOUT==0)
{lcd.setCursor(13,1);
lcd.print("OFF");}
else
{lcd.setCursor(13,1);
lcd.print("ON");}
}
//The menu it's represented   by a matrix and two variables i and j and according to their position the LCD screen it's showing a certain information.



if(kIN==1)
digitalWrite(valve1, HIGH);
else
digitalWrite(valve1, LOW);

if(kOUT==1)
digitalWrite(valve2, HIGH);
```

```
else
digitalWrite(valve2, LOW);
//kIN represent the status of the input valve where if the value it's 1 the valve it's open and close for 0.
kOUT is working after the same principle but it's controlling the output valve
}


// function that executes whenever data is received from master
// this function is registered as an event, see setup()
void receiveEvent(int howMany)
{
  while( Wire.available()) // loop through all but the last
  {
    x = Wire.read();    // receive water flow value
    y = Wire.read();    // receive water flow value
  z = Wire.read();    // receive the distance from the ultrasonic sensor
    }
}


int read_LCD_buttons()
{
 adc_key_in = analogRead(0);      // read the value from the sensor
 if (adc_key_in > 1000) return btnNONE; // We make this the 1st option for speed reasons since it will be
the most likely result
  if (adc_key_in < 50)   return btnRIGHT;
 if (adc_key_in < 250)  return btnUP;
 if (adc_key_in < 450)  return btnDOWN;
 if (adc_key_in < 650)  return btnLEFT;
 if (adc_key_in < 850)  return btnSELECT;
 return btnNONE;  // when all others fail, return this none
}
```