People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research

Ecole Nationale Polytechnique

Electronics Department

In partial fulfillment of the requirement for the
Engineer's Degree
(Electronics Engineering)

Development of a Measurement System for Hydraulics

Abdelhak BOUDEHANE
Youssouf SAMEUT BOUHAIK

Supervised by:
AP. Mourad ADNANE
AP. Rabie MESSAHLI

Publicly presented and discussed on 22/06/2016

Jury Members:

President	Pr. Adel BELOUCHRANI	ENP Algiers
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ملخص

القياس هو المشكل الرئيسي في مختلف مجالات العلوم. تحديداً، البحوث الخاصة بعلوم السوائل تتعلق مباشرة بمعرفة عدة خصائص مهمة للمادة. علاوة على ذلك، مشروعنا يعتمد على القياس المستمر لارتفاع السوائل وضغطها.

سابقاً، تم اقتراح عدة حلول تقليدية باستعمال الطرق الميكانيكية للقياس مثل الأنابيب على شكل U لقياس الضغط وكذلك المسطرات العادية لقياس الإرتفاع. هذه الطرق، بالإضافة إلى امتلاكها ثوابت زمن بطيئة ما يعني تجاوبا بطيئا، فهي تقدم هامش خطأ عريض. من جهة أخرى، تحليل القياسات يحتاج إلى حسابات رياضية وتمثيلات بيانية. هذا قد يضيع الكثير من الوقت ويمنع إمكانية التصوير والتحليل لحظيا.

في هذه الوثيقة، نقترح حلا إلكترونيا متكونا من مجموعة من أجهزة الإستشعار لقياس ارتفاع وضغط السوائل لحظيا بدقة عالية وهامش خطأ أصغر. هذه الأجهزة متركزة حول جهاز متحكم مهمته معالجة البيانات القادمة من مختلف أجهزة الإستشعار والتحكم في سير العملية الكلية. بالإضافة لذلك، يقوم بإرسال البيانات على الكمبيوتر عبر سلك USB لغرض استعراض، تسجيل وتمثيل هذه القيم بيانيا. معالجة هاته البيانات على جهاز الكمبيوتر يكون عبر واجهة مرئية تمثل الجانب البرمجي المضاف للجانب المادي مكونين معا المشروع الكامل.

الكلمات المفتاحية: مائع، إرتفاع، ضغط، قياس، جهاز استشعار.

Résumé

La mesure est actuellement un des problèmes majeurs dans les domaines scientifiques. Particulièrement, les recherches en hydraulique dépendent directement de la connaissance de certains paramètres importants qui sont variables. Un système hydraulique (pompe à injection d'air – airlift) qui nécessite la mesure continue de la pression d'air et du niveau de l'eau nous a été proposé comme problème.

Précédemment, des solutions traditionnelles ont été proposées utilisant des méthodes de mesure mécaniques comme le manomètre (tube en U) pour la pression et une règle ordinaire pour la mesure de niveau. Non seulement ces méthodes offrent des temps de réponse lents, mais aussi ils introduisent une marge d'erreur étendue. En plus, l'analyse des mesures nécessite des calcules mathématiques et des tracés de graphes. Cela élimine la possibilité de la visualisation et de l'analyse de la mesure en temps réel.

Dans ce mémoire, nous proposons une solution électronique constituée d'un groupe de capteurs qui mesurent la pression et le niveau d'eau en temps réel avec plus de précision et une marge d'erreur plus fine. Ces capteurs entourent un microcontrôleur qui a pour fonction le traitement de données venant de ces capteurs et la commande de tout le processus. En outre, les données sont transmises du microcontrôleur vers l'ordinateur via un câble USB pour visualiser, enregistrer et tracer les graphes. La gestion des données au niveau de l'ordinateur se fait par une application ayant une interface graphique qui représente la partie software ajoutée à la partie hardware pour former tout le système.

Mots clés : Airlift, niveau, pression, mesure, capteur.

Abstract

Measurement is actually a major problem in scientific fields. Particularly, hydraulic researches depend directly on the knowledge of certain important and variable parameters. A hydraulic system (airlift pump) that requires a continuous measurement of air pressure and water level has been proposed to us as a problem.

Previously, traditional solutions have been proposed using mechanical measurement methods such as the U tube manometer for pressure and an ordinary ruler to measure level. These methods, as well as having slow time constants which means slow response, introduce also a wide error margin. Likewise, the measures analysis needs mathematical calculation and graphics plotting. This removes the possibility of the measurements' real-time visualization and analysis.

In this document, we propose an electronic solution consisting of a group of sensors measuring pressure and water level in real time with higher precision and a smaller error margin. These sensors surround a microcontroller whose function is the processing of the data coming from the different sensors and the controlling of the whole process. Additionally, the data is sent from the microcontroller to computer through USB cable in order to visualize clearly, register and plot the values. The management of data in the computer is done by an application with a graphic interface that represents the software part added to the hardware part to form the whole system.

Key words: Airlift, level, pressure, measurement, sensor.

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Introduction

As known, the finality of engineering is the resolving of practical problems such as measurement. This is the starting point of our project that meant to be an electronic solution for a hydraulic system's problem. This system is a test prototype for airlift systems. It is used to study the influence of injecting compressed air into a liquid and determine the relation between the injected air flow and the liquid's flow (see figure 0.1).Hence, it is necessary to measure the compressed air pressure that is related to air flow and the liquid's level that is related to fluid flow. In this test prototype, the fluid used is water but real airlift systems are used mainly in oil extraction.

Electronic measurement of the previously mentioned parameters is the only practical solution due to the small devices' size and their efficiency. In this case, the electronics engineer's task is to study the system within all the influencing parameters, to propose the measuring system with the best quality – price ratio (choice of sensors, devices, etc.), to exploit the measuring system, to test it and to evaluate its performance with the definition of its error margin

Face to a measurement problematic, the theoretical study gives a general idea within a theoretical range that should be verified with practical values. The understanding of our system is very important in evaluating any measurement system.
This thesis is a presentation to the different concepts in relation to the problematic system we faced and the solution proposed.

The first chapter itemizes the different measurement methods used in hydraulics and cites their principles. It explains also the physical characteristics of the main phenomena interfering in the system and the measuring methods.

In the second chapter our explication digs deep in the technical concepts of the devices used in order to solve the problematic situation that we have faced. It gives details about the used sensors such as the fields of application, principle of detection, range and limitation. Furthermore, we have explored the microcontroller's architecture and serial communication principle.

In the third chapter we explore the practical experiments and the results found with some analysis of the situation and evaluation of the system performance. The error calculation also was introduced in both previous and actual methods in order to enlighten the improvement in the measuring precision.

The fourth chapter gives a future outlook, opening the door to more development to the different parts of the system. It mentions also the different problems faced during the project and the solutions proposed. New ideas have been proposed to improve the system's functioning.

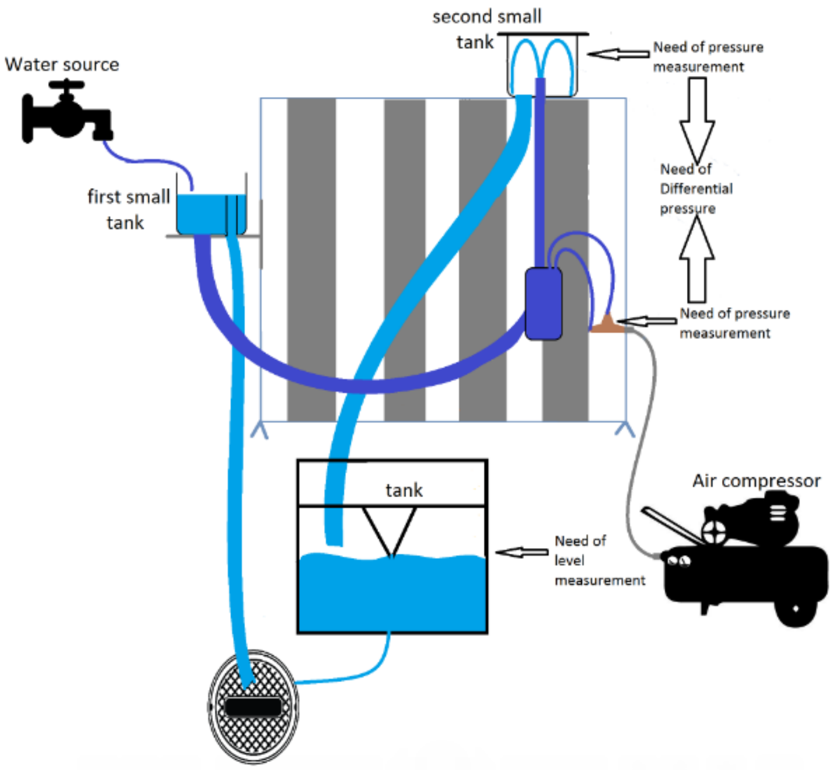


Figure 0.1: The hydraulic system and its problems.

Chapter 1

General Concepts

1.1 Fluid definition

A fluid is a substance that cannot resist a deformation force or shearing forces (which act tangentially to a surface), it moves (flows) under the action of that force. Its shape will change continuously as long as the force is applied, unlike a solid can resist a deformation force while at rest [1]. We can distinguish generally two kinds of fluid:

1.1.1 Liquid

A liquid is a fluid that takes the shape of its container, with a constant volume and a strong cohesive force which makes it almost incompressible.

1.1.2 Gas

A gas is a fluid that has separate particles and a weak cohesive force, it has no constant volume and it's free to expand and move.

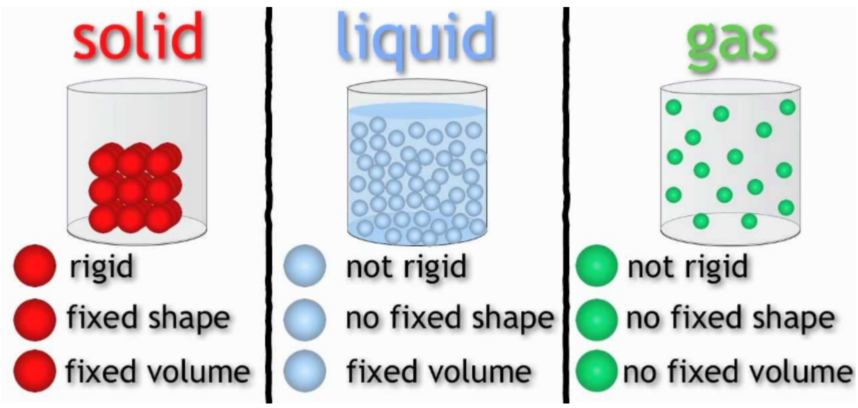


Figure 1.1: The different phases of matter [2].

1.2 Fluid properties

The property of any system is the characteristic that makes it describable, for the fluids, we can define fluid properties and parameters, as continuous point functions, only if the continuum approximation (view it as a continuous, homogeneous matter with no holes) is made [3]. This requires that the physical dimensions are large compared to the fluid molecules. We can count several properties:

1.2.1 Fluid flow

The fluid flow can be measured by determining the quantity of the liquid moved, using many methods, like comparing to multiple fixed volumes, from the velocity or pressure of the fluid over a specific area or utilizing the force produced facing a known constraint.

1.2.2 Classification of Fluid Flow

If we look at a fluid flowing under normal circumstances - a river for example - the conditions at one point will vary from those at another point (e.g. different velocity) we have non-uniform flow. If the conditions at one point vary as time passes then we have unsteady flow.
Under some circumstances the flow will not be as changeable as this. The following terms describe the states which are used to classify fluid flow:

- *Uniform flow:* If the flow velocity is the same magnitude and direction at every point in the fluid it is said to be uniform.
- *Non-uniform:* If at a given instant, the velocity is not the same at every point the flow is non-uniform. In practice, by this definition, every fluid that flows near a solid boundary will be non-uniform - as the fluid at the boundary must take the speed of the boundary, usually zero. However if the size and shape of the cross-section of the stream of fluid is constant the flow is considered uniform.
- *Steady:* A steady flow is one in which the conditions (velocity, pressure and cross-section) may differ from point to point but do not change with time.
- *Unsteady:* If at any point in the fluid, the conditions change with time, the flow is described as unsteady.

In practise there is always slight variations in velocity and pressure, but if the average values are constant, the flow is considered steady. Combining the above we can classify any flow into one of four types:

a *Steady uniform flow:* Conditions do not change with position in the stream or with time. An example is the flow of water in a pipe of constant diameter at constant velocity.

b *Steady non-uniform flow:* Conditions change from point to point in the stream but do not change with time. An example is flow in a tapering pipe with constant velocity at the inlet - velocity will change as you move along the length of the pipe toward the exit.

c *Unsteady uniform flow:* At a given instant in time the conditions at every point are the same, but will change with time. An example is a pipe of constant diameter connected to a pump pumping at a constant rate which is then switched off.

d *Unsteady non-uniform flow:* Every condition of the flow may change from point to point and with time at every point. For example waves in a channel [1].

According to the type of movement of the fluid in a pipe we can classify the fluid flow into two major classes:

a. Laminar flow: Where the fluid moves slowly in layers in a pipe, without much mixing among the layers. Typically occurs when the velocity is low or the fluid is very viscous.

b. Turbulent flow: Opposite of laminar, where considerable mixing occurs, velocities are high.

Laminar and Turbulent flows can be characterized and quantified using Reynolds Number (dimensionless quantity defined as the ratio of inertial forces to viscous forces, it represents the relative relevance of these forces for given flow conditions, so as $R_e = \dfrac{\rho v L}{\mu}$ with ρ is the density of the fluid, v is the maximum velocity of the object relative to the fluid (m/s), L is travelled length of the fluid and μ is the dynamic viscosity(kg/m.s)[4], such as: $R_e < 2000$ for Laminar flow.
$R_e > 4000$ for Turbulent flow.

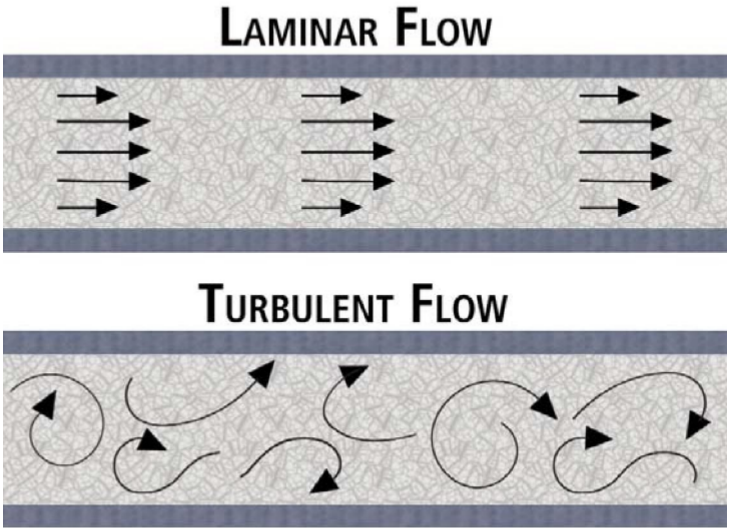


Figure 1.2: The difference between Laminar and Turbulent flow [5].

1.2.3 Flow velocity

The flow velocity of a fluid is generally described using a vector quantity, and it is more difficult to determine it when the flow is turbulent than when it is laminar. The velocity of a fluid is the rate of change of position per unit of time. In mathematical terms, the velocity of a fluid is the derivative of the position vector of the fluid with respect to time, and is therefore itself a vector quantity. The flow velocity vector is a function of position, and if the velocity of the fluid is not constant then it is also a function of time. As a vector quantity, fluid velocity must have at least one non-zero directional component and may have up to three non-zero directional components. The velocity vector has non-zero components in any orthogonal direction along which motion of the fluid occurs[6]. The mathematical expression for the velocity of a fluid in motion is shown in the next equation:

$$\vec{v} = \frac{d\vec{r}}{dt} \quad \text{with} \quad \vec{v} = \left\langle \frac{d\vec{r_x}}{dt}, \frac{d\vec{r_y}}{d}, \frac{d\vec{r_z}}{dt} \right\rangle \tag{1.1}$$

1.2.4 Pressure P

Pressure of a fluid is the force it exerts perpendicular to the surface of an object per unit of that surface. It is expressed by several units, like the Pascal (Pa) (one newton per square meter 1 N/m^2), the standard atmosphere (atm) (1 atm = 101 325 Pa), the bar (1 bar = 10^5 Pa). Mathematically:

$$Pressure = \frac{Force}{Area} \tag{1.2}$$

The pressure due to a liquid in liquid columns of constant density or at a depth within a substance is derived from equation 1.2 above, the weight of the column of liquid:

$$Force = Weight = mg = \rho V g \tag{1.3}$$

Replacing equation 1.3 in 1.2 we can conclude the general formula of pressure for liquid columns which is independent of the container shape.

$$P = \rho g h \tag{1.4}$$

With ρ is the density (Kg/m^3), m is the mass (Kg), V is the volume (m^3), g is acceleration of the gravity(m/s^2) and h is the liquid depth (m)

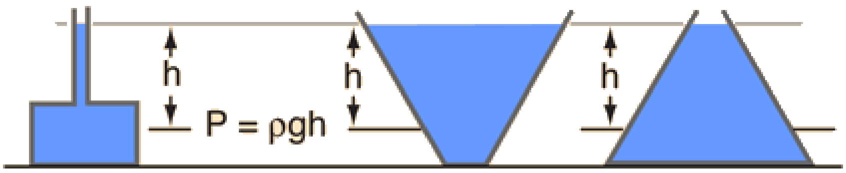


Figure 1.3: Static fluid pressure is independent of shape.

It is important to remark that the pressure depends only on the depth, not the amount of liquid present nor the volume.
Many applications benefit from the pressure measurement, like Altimeter, Barometer, Linear Variable Differential Transformers (LVDTs), PITOT tube, MAP sensor, Sphygmomanometer, etc.

1.2.5 Viscosity

The viscosity represents the internal resistance of a fluid to flow. It defines the fluid strain rate caused by a gradual shear stress and describe the thickness of a given fluid. The reciprocal of the viscosity is called the fluidity, the dimensions of dynamic viscosity are force times time divided by area and its unit accordingly, is $\frac{N.s}{m^2}$

A Newtonian fluid has a linear relationship between shear stress and velocity gradient. Figure 1.4 indicates how the fluid viscosity depends on temperature. As the temperature increases, the viscosity of all liquids decreases, while the viscosity of all gases increases. Viscosity measurement is an important tool for many applications, as for food industry,

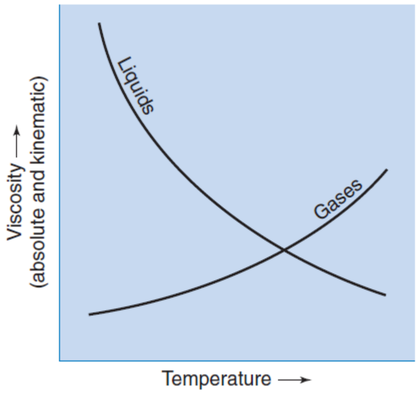


Figure 1.4: The influence of temperature on the fluid viscosity [7].

Cosmetics, Ink, Paint, Plastic manufacturing, Electronics PCBs, etc.

1.2.6 Density

The density is a physical property of matter, defined as the quantity of matter contained in a unit volume of the substance, in another word, it describes how tightly matter is crammed together.The density of a liquid depends strongly on the temperature.. Since pure substances have unique density values, measuring the density of a substance can help identify that substance. Mathematically:

$$Density = \frac{Mass}{Volume} \tag{1.5}$$

Densities of some Common Materials are shown in the next table:

20 °C, 1 atm	Air	Water	Hydrogen	Mercury
ρ (kg/m^3)	1.20	998	0.0838	13.580

Table 1.1: Densities of some common Materials [3].

Density measurement has been used for several applications, such as Archimedes' principle, Lava Lamps, Petroleum, Pharmaceuticals, Flavor and Fragrances, Chemical Plants, etc.

1.2.7 Compressibility

A useful concept used extensively in determining the relative change in volume of the fluid due to a variation of its pressure. The gas compressibility should not be confused with the compressibility factor, which is the deviation factor from ideal gas behavior. Mathematically, it can be expressed as: :

$$\beta = \frac{1}{V}\frac{\partial V}{\partial P} \tag{1.6}$$

When V is the volume, and P is the pressure. Compressibility is used in the Earth sciences to quantify the ability of a soil or rock to reduce in volume with applied pressure, it used also in aerodynamics, as the airflow exceeds the speed of sound, the design of aircraft will be bound to many aerodynamic effects.

1.3 Liquid Level Measurement

Many techniques are available for level measurement, each with its own advantages and limitations. The best selection depends on the nature of the specific application, including the process to be measured, the degree of accuracy and dependability desired, and economic considerations and constraints.

Level applications have changed somewhat in recent years because of the dynamic economic constraints and stipulations brought about by material cost, international market strategies, and product changes. In the past, the measurement of level did not usually demand highly accurate and sensitive devices. Applications generally require certain specifications:

- High accuracy.
- Easy operation and maintenance.
- Testability.
- Self monitoring and error signalling.
- Easily understandable functionality.
- Communication ability.

Like many variables, level can be measured by both direct and inferred methods. Direct methods employ physical principles, such as fluid motion, floats and buoyancy, and optical, thermal, and electrical properties [8].
The figure 1.5 summarizes the different methods to measure the level.

Inferential methods involve the use of hydrostatic head, weight quantities, radioactive properties, density and sonic detectors. The selection of a particular level device, however, is generally made with regard to characteristics more closely related to requirements of a specific application.

1.3.1 Visual Measurement Methods

Measuring level by visual means is the most direct and simple method. Making benefit from the ability of detection of level by sight observation using a dipstick or a gauge. In the face of being straightforward, accurate and reliable, nevertheless, visual measurement is normally limited to backup measures or to applications where constant monitoring is either unnecessary or is undesirable. Figure 1.6 shows a visual method using a dipstick:

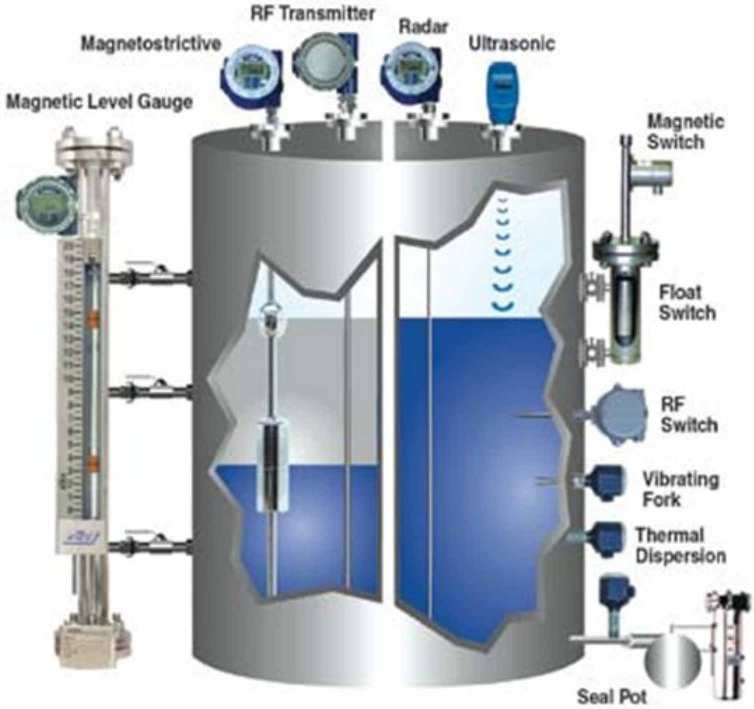


Figure 1.5: Liquid level measurement methods [9].

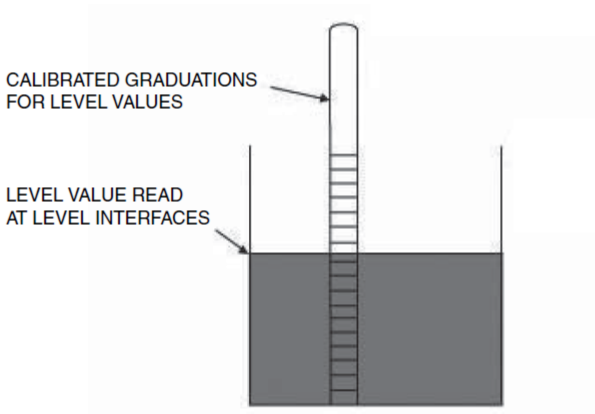
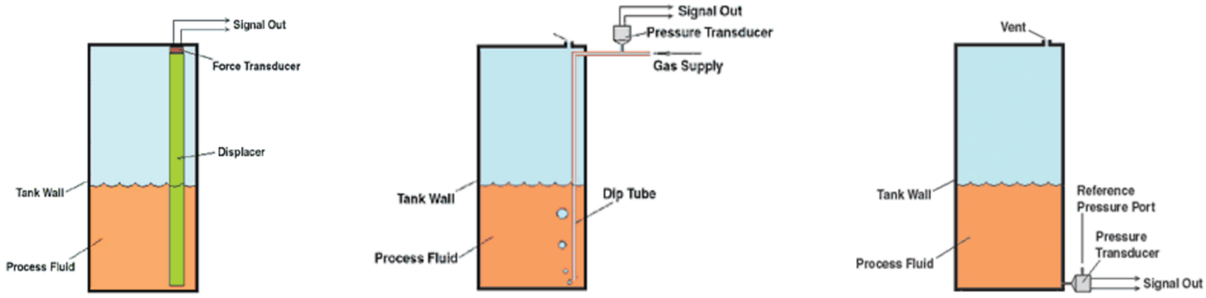


Figure 1.6: Visual level measurement method using a dipstick.

1.3.2 Hydrostatic Devices

Hydrostatic pressure sensor is considerably the most used sensor in level measurement. For the principle, a pressure transmitter is mounted on a specific level and measures the pressure caused by the weight of the liquid, using the hydrostatic paradox (the water levels in both side of a tube are identical independently of their shape) it can measure the level by the weight of the liquid column above it. the ability of being mounted externally makes it suitable for this contest, due to the hydrostatic effect of non-flowing fluids. Many devices have been developed in order to replete the industrial market such as, Displacers, Bubblers and differential-pressure transmitters, which are shown respectively in figures 1.7a, 1.7b and 1.7c:



(a) Displacement gauge (b) Bubbler device (c) Differential pressure

Figure 1.7: Different hydrostatic devices for level measurement [9]

Hydrostatic devices have many advantages, like the high reliability independent of fluid characteristics such as conductivity, dielectric coefficient or viscosity, a robust and simple installation. However, it encounters certain limitations for more accurate application and also for the bulk material.

1.3.3 Float Level Sensors

Float devices use a mechanical switch which can be controlled either directly (mechanically) or using a magnetic connection. In such a device, the only portions of the system in contact with the corrosive material in the tank are the float. The float design is determined by the process fluid's specific gravity, pressure, and temperature. The float, carrying a set of strong permanent magnets, rides in an auxiliary column (float chamber) attached to the vessel by means of two process connections. This column confines the float laterally so that it is always close to the chamber's side wall. As the float rides up and down with the fluid level, a magnetized shuttle or bar graph indication moves with it, showing the position of the float and thereby providing the level indication. The system can work only if the auxiliary column and chamber walls are made of nonmagnetic material, as shown in figure 1.8.

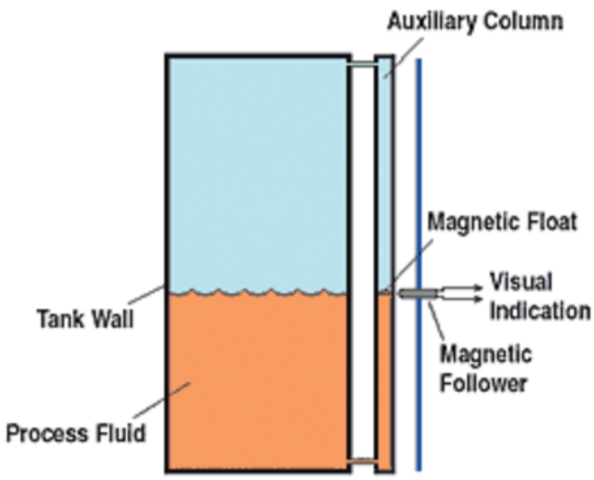


Figure 1.8: Magnetic level gauge uses a magnetically coupled shuttle [9].

Float level sensors are not recommended with high viscosity liquids or liquids that adhere to the stem or floats, or materials that contain contaminants such as metal chips, etc.

1.3.4 Capacitance Level Sensor

Unlike the usual capacitor which has two small parallel plates separated by a dielectric. Capacitance Level Sensors has one plate typically as a probe while the other plate comprises the side of the level vessel, or a reference probe or plate if the vessel is made of insulating material. Those sensors use the fact that process fluids generally have dielectric constants, significantly different from that of air ($\varepsilon_{air} \simeq 1$), as the fluid level rises and fills more of the space between the plates, the overall capacitance rises proportionately. The overall capacitance is measured by a specific circuit in order to provide a continuous level measurement. The sensor installation is shown in figure 1.9:

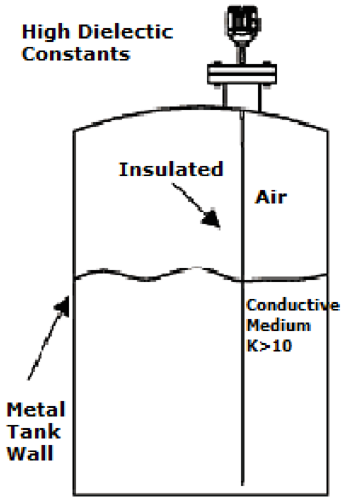


Figure 1.9: Capacitive level sensor measures the change in capacitance between two plates produced by changes in level. [9].

Capacitive level sensors are one of the most non-limited techniques with a wide range of measurement conditions, these sensors have a robust structure with no moving part. However, these techniques are intrusive which make it exposed to large errors.

1.3.5 Sonic and Ultrasonic Transducers

Ultrasonic measuring uses ultrasound waves to detect level. Ultrasound waves are basically specific sound waves with higher frequencies than audible limit of human capability of hearing (about 20 kHz), except that the ultrasound waves have exactly the same physical characteristics of the sound waves.

Ultrasound waves like other mechanical waves suffer when propagating in different materials from decrease in acoustic energy called attenuation due to three principle causes: divergence, deflection and absorption depending on the type of material whom the ultrasound wave is propagating through.

Sonic/Ultrasonic measuring is one of the best options in case when the contact with the fluid is undesirable. The Operating principle of both is generally the same, the only difference is in the frequency range (Ultrasonic around 20 kHz to 200 kHz, while sound operates around 20 kHz and below).

Ultrasonic level sensors (see figure 1.10) determine the distance between the transducer and the liquid surface using the time that the reflected ultrasound pulse takes to return to the transducer. Successful measurement depends on the transducer's position, so that the internal structure of the vessel will not interfere with the wave path. The

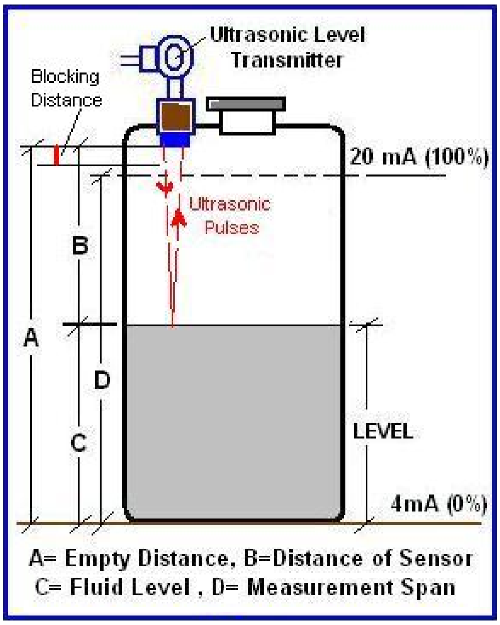


Figure 1.10: General schema of fluid level measurement [10].

ultrasonic sensor has many advantages, beside that the sensor doesn't come in contact with the liquid, the ultrasonic sensor is an electronic device, and that give it the possibility to improve it adding an electronic circuit in order to analyse and process the output signal and send it to the computer using a serial communication. However this technique still suffer from various influences that affect the reflected signal. Things such as dust, temperature, surface turbulence, and ambient noise. The Ultrasonic Level Sensor is the one we chose in this project, and it will be detailed with the whole processing circuit in the next chapter.

1.3.6 Radar Level Sensor

The principle of the radar sensor is generally similar to the Ultrasonic sensor, the fundamental difference resides in the working frequency, while Radar sensors work in microwaves frequencies. The sensor emits a microwave pulse towards the liquid. This pulse is reflected by the surface of the liquid and received by the sensor. From the time of flight of the signal, the level can be calculated.

$$Distance = \frac{\text{Speed of light} \cdot \text{Time delay}}{2} \tag{1.7}$$

The antenna design is of utmost importance to ensure performance despite contamination from viscous or condensing deposits. As shown in figure 1.11 two different installations are generally used, guided-wave radar using a probe when the process liquid permittivity is low, and non-contact wave radar that send in an open space.

The radar sensors have several advantages, such as high accuracy, non-contact installation and the ability of measurement through plastic tanks, but its major disadvantage is the cost, where this sensors are very expensive.

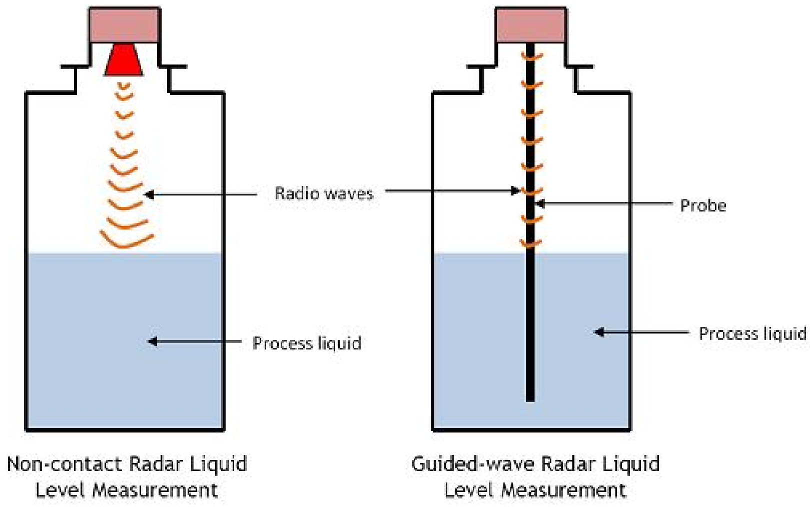


Figure 1.11: Operating Principle of guided-wave and non-contact wave Radar [11].

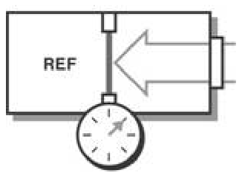
1.4 Pressure Measurement

There are a variety of techniques that have been developed based on various principles in order to respond to all measurement conditions. They can be either direct-reading gauges influenced directly by the pressure, or indirect-reading gauges dependant on other pressure parameters. Generally there are three ways for measuring pressure shown in figure 1.12:

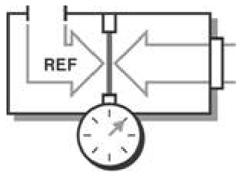
• *Absolute Pressure:* The absolute measurement method is relative to 0 Pa. The pressure being measured is being acted upon by atmospheric pressure in addition to the pressure of interest. Therefore, absolute pressure measurement includes the effects of atmospheric pressure. This type of measurement is well-suited for atmospheric pressures such as those used in altimeters or vacuum pressures.

• *Gauge Pressure:* Gauge and differential measurement methods are relative to some other dynamic pressure. In the gauge method, the reference is the ambient atmospheric pressure. This means that both the reference and the pressure of interest are acted upon by atmospheric pressures. Therefore, gauge pressure measurement excludes the effects of atmospheric pressure.

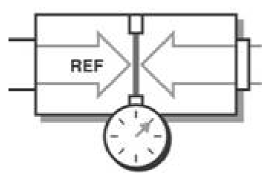
• *Differential Pressure:* Differential pressure is very similar to gauge pressure; however, the reference is another pressure point in the system rather than the ambient pressure. One can use this method to maintain a relative pressure between two vessels such as compressor tank and associated feed line [12].



(a) Absolute Pressure



(b) Gauge Pressure



(c) Differential Pressure

Figure 1.12: Pressure Sensor Diagrams for Different Measurement Methods [12]

Using one of these techniques, a variety of pressure sensors have been developed:

1.4.1 Liquid Column Gauge (U-tube Manometer)

Pressure sensors using liquid columns in vertical or inclined tubes are called manometers. Probably one of the most common and oldest method for measuring pressure. The column level will change until its weight is in equilibrium with the differential pressure between the two ends of the tube, each end is connected to the region of interest while the reference pressure is applied to the other. The difference in liquid level represents the applied pressure, see figure 1.13.

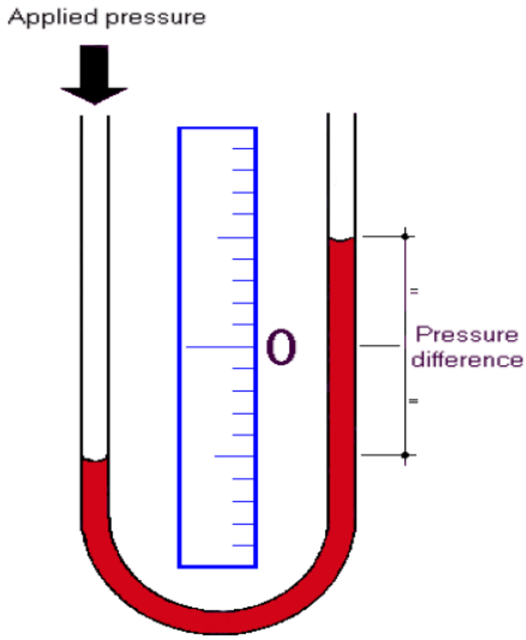


Figure 1.13: Principle of the U-tube manometer [13].

The difference of pressure between the two level of a vertical U-Tube manometer can be expressed as:

$$\Delta P = \rho g \Delta h \tag{1.8}$$

Manometers have many advantages, such as their low cost comparing to other devices, accuracy, they don't need any power supply and they are simple to install and operate. But still have problems of slow response, moving reference and limited to small pressure differences.

1.4.2 Pressure Transducers

A pressure transducer is a device which converts an applied pressure into a measurable electrical signal proportional to that pressure. It consists of two main parts, a diaphragm (elastic material) which will deform when exposed to an applied pressure and an electrical circuit which detects the deformation and converts it into a measurable electrical signal. The diaphragm can be formed into different shapes depending on the measuring technique and range of pressures desired. This often involves a diaphragm combined with an electrical device that uses a resistive, capacitive, or inductive principle.

A Piezoresistive Strain Gauge

This device contains strain gauges with an integral sensing diaphragm whose the gauge is bonded to it's contacted surface. Any change in pressure will be noticed as a instantaneous deformation on the level of the diaphragm producing a change of the resistance of the strain gauge (the piezoresistive effect) which is represented as an output voltage proportional to that pressure, see figure 1.14.

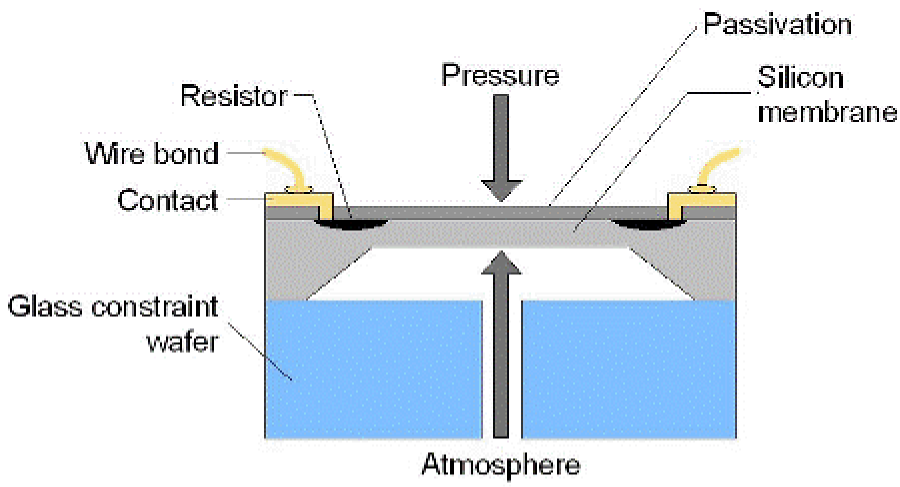


Figure 1.14: Basic design of piezoresistive silicon pressure sensors [14].

One of the disadvantages of these devices is that the resistors and the pressure sensitivity are dependent on temperature, and change over the operating temperature range of the sensor. Calibration and compensation techniques can be used to correct the errors of the sensor. The conventional method of correction uses passive resistor networks or active components such as diodes and transistors. The approach allows overall accuracies of the order of 3% of the measurement range to be achieved, for more details see [14].

B Capacitance Pressure Transducer

This transducer has a precision diaphragm moving between fixed electrodes causing a capacitance changes related to the differential pressure. This change in capacitance will be converted into a measurable signal. Inductive Pressure. Metal, silicon, and ceramic diaphragms are the most used.

C Electromagnetic Pressure Transducer

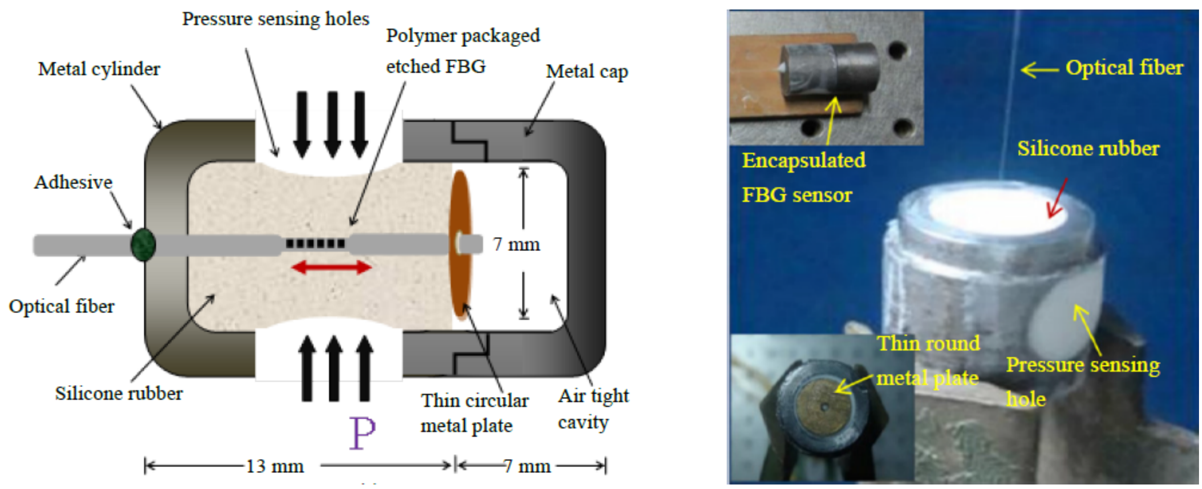
An Electromagnetic Pressure Transducer uses the principle of inductance to generate a linear movement of a ferromagnetic core from the movement of a diaphragm. The movement of the core vary the induced current (eddy current) generated by a coil supplied by an AC power on another secondary coil. This change is then converted into a measurable signal.

1.4.3 Optical Pressure Sensor

Optical Pressure Sensor commonly based on Fiber Bragg Grating (FBG) technology (a type of light reflector by varying the refractive index of the fiber core) has been developed to detects the pressure difference with high sensitivity and resolution using the variation of the reflective index and measuring the Bragg wavelength shift of the FBG with respect to the change in pressure.

In this FBG sensor, the Bragg wavelength (center wavelength of the reflected signal) is linearly dependent on the product of the grating period and the core index of refraction. Changes in strain or temperature to which the optical fiber is subjected linearly shift this Bragg wavelength. This type of sensor is thus insensitive to power fluctuations in the source.

Two approaches are commonly used: one consists of attaching the FBG fiber to a flexible diaphragm either orthogonally or in the diaphragm plane in areas where the strain is maximal. In both cases, such designs always imply bulky sensors, often limited to high pressure ranges which are however acceptable for applications in civil engineering or in the oil and gas industry where sensor size is not a real issue. Another interesting approach consists of mounting the FBG sensor in cylindrical assemblies so that increased pressure sensitivity is achieved though mechanical amplification schemes [15]. A general design is proposed by [16] in figure 1.15.



(a) Schematic (b) Photograph

Figure 1.15: Polymer packaged FBG pressure sensor.

Fiber Bragg grating sensor system can offer lower cost, lower technical difficulties and higher accuracy at the same time. The sensor design and interrogation system are also much simpler than other systems. In addition fiber Bragg grating sensor has the ability to multiplex on a single optical fiber, for more details consult [15].

1.5 Flow Measurement

Flow measurement serves to quantify the fluid movement, and that can be fulfilled by many methods, we will summarize some of them below:

1.5.1 Electromagnetic Flowmeters

When an electrical conductor is moved in a magnetic field which is perpendicular to the direction of motion and to the conductor, an electrical voltage is induced in the conductor whose magnitude is proportional to the magnetic field strength and the velocity of the movement. This characterization of the laws of induction also applies to the movement of a conductive liquid in a pipe through a magnetic field [17]. This principle is known as Faraday's law and stated by the following equation:

$$EMF = B \cdot L \cdot V \cdot 10^{-8} \tag{1.9}$$

Where EMF is the electromotive force (Volt), B is the magnetic flux density ($V.s/cm^2$), L is the length of the conductor (cm) and V is the velocity of the conductor (cm/s).

Electromagnetic flow meters are best-suited for measuring flows of liquid metal such as sodium, mercury, potassium and liquids of poor conductors appeased of charged particles.
The operating principle of such devices is shown in figure 1.16

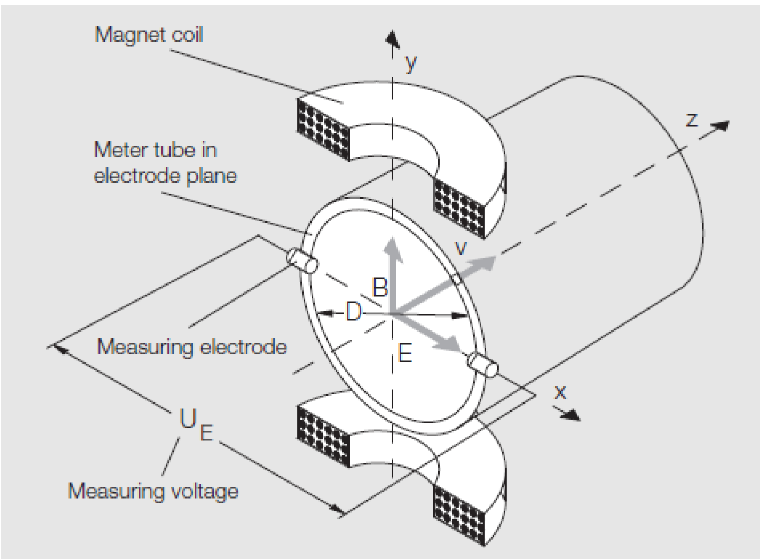


Figure 1.16: Operating Principle of an Electromagnetic Flowmeter [17].

1.5.2 Ultrasonic Flowmeters

An ultrasonic flow meter is a device used to measure the velocity of a fluid using ultrasound waves to calculate the volume flow of the liquid. When a disturbance is created in the flowing fluid, it generates sound waves that propagates everywhere in the flow field. These waves travel faster in the flow direction (downstream) compared to the waves in the upstream direction. As a result, the waves spread out downstream while they are tightly packed upstream. The difference between the number of waves in upstream and downstream is proportional to the flow velocity. There are two basic methods for ultrasonic flow measurements:

A Transit Time Method

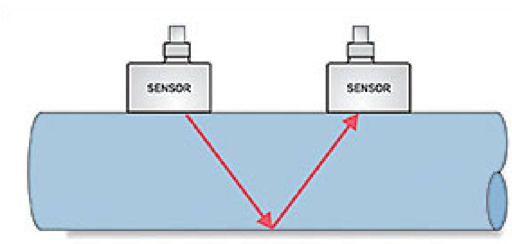
This method involves two transducers located at certain distance l that alternatively transmits and receive ultrasonic sound waves, in the direction of the flow as well as in the opposite direction. The travel time for each direction can be measured accurately and the difference Δt can be estimated (figure 1.17a). The average flow velocity V can be determined from the following relation (when K is a constant):

$$V = K \cdot l \cdot \Delta t \tag{1.10}$$

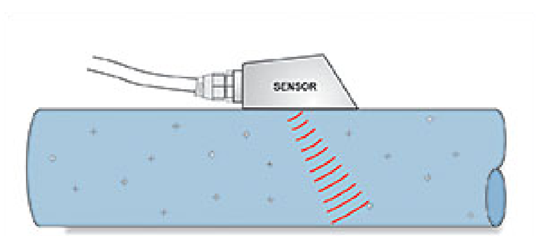
B Doppler Effect Method

It measures average velocity along the sonic path. The piezo-electric transducers placed outside the surface of the flow transmits sound waves through the flowing fluid that reflects from the inner wall of the surface. By capturing the reflected signals, the change in frequency is measured which is proportional to the flow velocity (figure 1.17b) [18].

Since the sound velocity is a function of the temperature, pressure and composition of the measuring medium, even small changes in these variables affect the Doppler shift and an appropriate compensation must be provided.



(a) Transit Time Method



(b) Doppler Effect Method

Figure 1.17: Basic principle of an ultrasonic flowmeter [19].

1.5.3 Vortex Flowmeters

When a flow stream encounters an obstruction in its path, the fluid separates and swirls around the obstruction. This leads to formation of vortex and it is felt for some distance downstream. It is a very familiar situation for turbulent flows and a short cylinder placed in the flow sheds the vortices along the axis. If the vortices are periodic in nature, then the shedding frequency is proportional to the average flow velocity. In other words, the flow rate can be determined by generating vortices in the flow by placing an obstruction along the flow and measuring the shedding frequency. The operation principle is shown in fig 1.18.

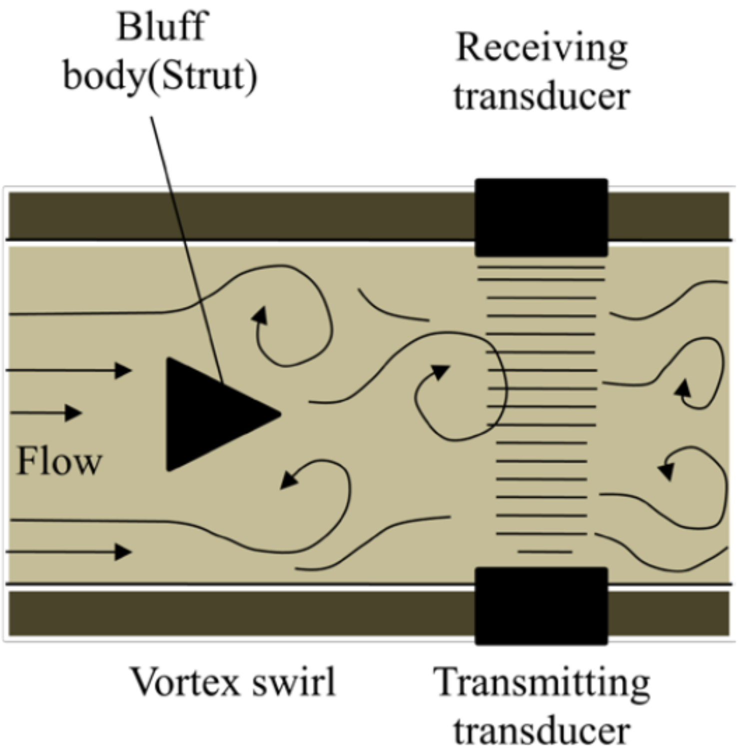


Figure 1.18: Operating Principle of a Vortex Flowmeter [18].

Accurate measurement in a flow environment is always desired in many applications. The basic approach of the given measurement technique depends on the flowing medium (liquid/gas), nature of the flow (laminar/turbulent) and steady/unsteadiness of the medium. Accordingly, a general comparison between common methods is show in figure 1.19 below.

✓ Suitable (✓) Suitable under conditions	Electromagnetic Flowmeters	Variable Area Flowmeters	Ultrasonic Flowmeters	Mass Flowmeters	Vortex Flowmeters	Flow Controllers
Liquids						
Liquids (e.g. water)	✓	✓	✓	✓	✓	✓
Low flow rates (< 2 l/h)	✓	✓		✓		
High flow rates (> 100.000 m3/h)	✓		✓			✓
Non-conducting liquids		✓	✓	✓	✓	(✓)
Viscous liquids	✓	(✓)	(✓)	✓	(✓)	(✓)
Gases						
Industrial gases		✓	✓	✓	✓	
Low flow rates (<20 l/min)		✓	(✓)	✓		
High flow rates		(✓)	✓	✓	✓	
Steam		(✓)	✓		✓	
Special applications						
Slurry, solid-laden media	✓			(✓)		
Emulsions (oil/water)	(✓)	✓	(✓)	✓	(✓)	(✓)
Corrosive liquides (acids, alkalis)	✓	✓	✓	✓	(✓)	(✓)
Corrosive gas flows		(✓)	(✓)	(✓)	(✓)	
Bi-directional measurement	✓		✓	✓		(✓)
Version						
2-wire	✓	✓			✓	✓
4-wire	✓		✓	✓		

Figure 1.19: Global overview of flow measurement methods [20].

1.6 Choosing the right sensor

In order to know the performances of a sensor, it is necessary to change its environment conditions and observe how these changes in different characteristics affect the device's output. Selecting the right sensor can be a hard and daunting task, it evolves many considerations and factors affecting the performance of the sensor like:

0. Type of Sensor: we have to determine precisely the exact parameter to measure.
0. Define the typical and extremes of the environmental conditions (Minimum and maximum, temperature, pressure, humidity, shock, vibration, etc.).
0. The cost of the Sensor which of course vary noticeably depending on the desired requirements.
0. Determine which sensing technology options suit the measurement requirements.
0. Determine the measured range, its extremes and limitations.
0. How accurate does the measurement need to be.
0. Control interface and communication ability.

1.7 Calibration

The process and apparatus used to find out if a measurement is accurate enough is called calibration. It is defined as a set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a measure or a reference material, and the corresponding values realized by standards. It is generally agreed to have less uncertainty than that in the result obtained. The error arising within the calibration apparatus and process of comparison must necessarily be less than that required. This means that calibration is often an expensive process. Conducting a good calibration requires specialist expertise.

The result of a calibration permits either the assignment of values of measurands to the indicators or the determination of corrections with respect to indications. Calibration can also determine other metrological properties, such as the effect of influence quantities. The result of a calibration can be recorded in a document, sometimes called a calibration certificate or a calibration report [21].

1.8 Conclusion

So many methods are used in hydraulics to measure level, pressure and flow. These methods are characterized by some parameters such as efficiency, implementation and price that evaluate their reliability and suitability to different applications. Only the study of all physical characteristics and interfering phenomena in each method can lead us to the appropriate one for each application.

Chapter 2

Technical Concepts of System Components

2.1 Ultrasonic transceiver

Ultrasonic transceivers are at the same time transmitter and receiver transducers that convert electrical signal into ultrasound waves (transmitter) and ultrasound waves into electrical signal (current/voltage). They are widely used in many fields due to their easy integration in electronic circuits and large usefulness. see figure 2.1.

Figure 2.1: Ultrasonic transceiver HC-SR04

2.1.1 Fields of application

Ultrasonic transceivers' use spreads over a large area of scientific fields: from engineering to scientific researches and from underwater detection to the medical field, it also takes place in other industry fields. We cite below some examples in the main fields where ultrasonic transceivers are required.

A Medical field

It is used in cases of: abdominal, cardiac, maternity, gynecological, urological and cerebrovascular examination, breast examination, and small pieces of tissue as well as in pediatric and operational review [22].

B Process industry

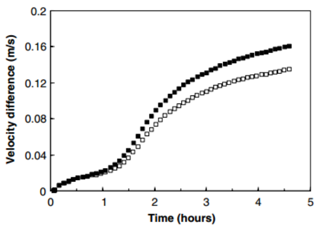
Conversion of gases, steams, liquids and solids, conversion of different forms of energy, separation, mixing and storage of products are among the many operations found in the process industry. The demand to control the processes leads to an extensive need of measurements (temperature, pressure, level, flow, etc).

However, process sensors have to meet requirements specific to the application. For example: when applications in the chemical industry are considered, a sensor has to resist aggressive media such as hot acids. Measurements in these harsh environments can advantageously be made using ultrasound, since it can usually penetrate the walls of vessels or pipes, thus allowing noninvasive measurements [23].

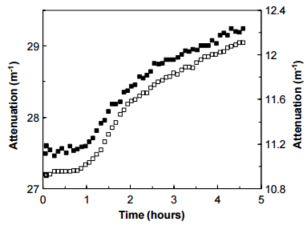
The main characteristic of ultrasonic sensors, which is supporting harsh environments and extreme process industry conditions pushes them to the top of the sensors used in this field.

C Food industry

Ultrasonic transceivers are also used in food industry and researches, from which we mention the studies of the gelation of milk. The ultrasonic velocity and attenuation through milk is related to the renneting of milk as shown in fig. 2.2a and 2.2b.



(a) Renneting of milk measured by ultrasound. The differences in ultrasonic velocities measured between cells 1 and 2 of the ultrasonic spectrometer at different frequencies.



(b) Renneting of milk measured by ultrasound. The attenuation of ultrasound in skim milk treated with rennet, as function of time, same conditions as in figure 2.2a

.

Figure 2.2: Measure of milk renneting using velocity and attenuation [24].

The difference in ultrasonic velocity between cells 1 and 2 and the ultrasonic attenuation in cell 1 are shown in Figs. 1 and 2 for milk treated with rennet at a concentration of 1 ml rennet per 100 ml milk. Both the ultrasonic velocity and the attenuation are affected by the enzymatic reaction and the subsequent clotting of milk. The ultrasonic velocity increased slowly during the first hour of the reaction, after which there was an increase in the slope of the curve, and finally the plot tended to flatten off at a value of about 0.16 m/s. The attenuation did not change significantly during the first part of the reaction, but then a sharp increase was seen followed by a levelling-off. When the concentration of rennet was increased to 3 ml per 100 ml, the first stage of the changes became shorter, because of the increased rate of attack of the enzyme on the casein micelles of the milk. Similar result profiles were obtained at the different frequencies which were used, although the values of attenuation were highly frequency dependent, as is normal for protein solutions.[24]

2.1.2 Level measurement

Considered as the main application of ultrasonic sensors, the distance or level measurement is very common and wide spread in the engineering field. The factors leading the usefulness of ultrasonic sensors in level measurement are their relatively low prices and their easy implementation in different types of circuits.

The principle of level measurement using ultrasonic sensor is very simple: the ultrasonic waves spread with a velocity of 340 m/s, traveling twice the distance between the sensor and the target (going and coming) in a time interval T. Hence, the equation of the distance D between the sensor and the target (level) is:

$$D = \frac{340 \cdot T}{2} \tag{2.1}$$

2.1.3 Level measurement using ultrasonic transceivers

Water level measurement, as mentioned above, is one of the most important measurements in hydraulics. The need to pursue, in real-time, and to register the water level in the interest of processing and plotting makes the electronic measurement using ultrasonic transceivers the best way to satisfy all requirements.

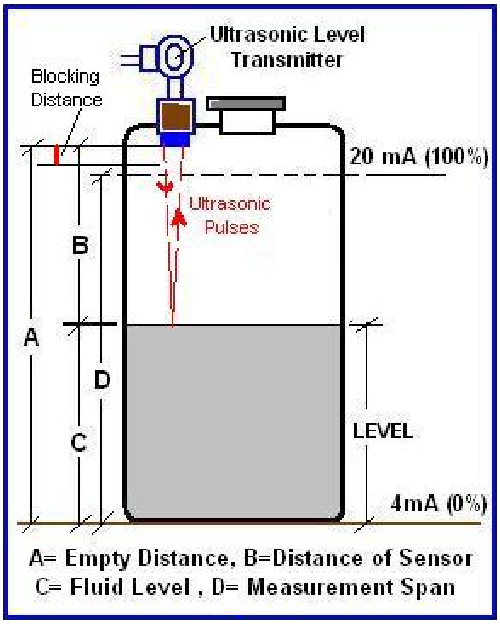


Figure 2.3: General schema of fluid level measurement [10].

In order to measure fluid level, the ultrasonic transceiver is placed above so that the ultrasound waves upcoming from the signal generator spread in vertical direction from the sensor down to the fluid surface then back upwards to the sensor within a time delay T as shown in figure 2.3.
The returning signal is delivered to the calculator in order to calculate the distance between the sensor and the fluid level knowing the ultrasound waves velocity and using the equation 2.1. The level is then calculated simply using subtraction.

However, the choice of the ultrasonic transceiver depends on the experimental conditions. This choice may remain relatively important according to the suitability of sensor's properties to the practical requirements. In our case, the quality-price ratio has led us to the module HC-SR04, which is widely used due to the properties that we will cite below.

2.1.4 Principle of ultrasonic transducer

A Basic principles of the ultrasonic transducer

Ultrasonic transducers operate based on both converse and direct effects of piezoelectric materials in which the vibration would be produced upon the application of a potential difference across the electrodes and then the signal would be generated when receiving an echo. Consequently, piezoelectric elements play a very important role in transducer technology. For specific applications, proper piezoelectric materials are chosen according to a number of factors such as their piezoelectric performance, dielectric properties, elastic properties and stability. A transducer rings at its natural frequency once it is excited by an electrical source. Since the piezoelectric material itself exhibits much higher acoustic impedance (30 MRayl) than that of biological tissue or water (1.5 MRayl), a substantial part of the acoustic energy would be lost at the rear interface and not directed into the forward direction, resulting in poor resolution and sensitivity, if not properly matched acoustically. The transducer is usually treated as a three–port network including two mechanical ports and one electrical port as shown in figure 2.4 [25].

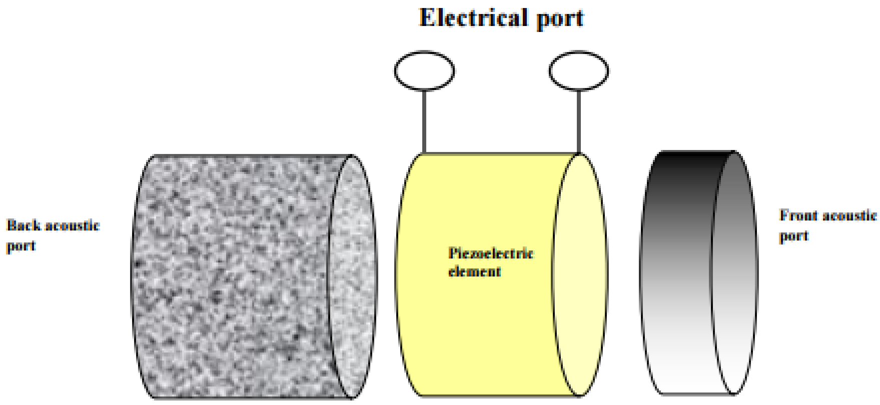


Figure 2.4: A three–port network of the transducer [25]

The mechanical ports represent the front and back surfaces of the piezoelectric element and the electrical port represents the electrical connection of the piezoelectric element to the electrical source. The front layer is known as an acoustic matching layer, which can improve the transducer performance significantly (Theoretical 100%). Transmission is shown to occur for a sinusoidal acoustic wave when the matching layer thickness approaches $\frac{\lambda_m}{4}$ and acoustic impedance of the matching layer material Z_m is :

$$Z_m = (Z_p Z_l)^{1/2} \tag{2.2}$$

where λ_m is the wavelength in the matching layer material, Z_p and Z_l are the acoustic impedances of piezoelectric material and the loading medium, respectively. For wide-band signal, the acoustic impedance of the single matching layer should be modified to be :

$$Z_m = (Z_p Z_l^2)^{1/3} \tag{2.3}$$

In fact, 100% transmission is impossible for only considering the front matching layer. Due to the acoustic mismatch between the air and the piezoelectric material, the reflected

wave reverberates inside the transducer element. This would cause long ring–down of the ultrasonic pulse, which is the so–called ringing effect. For imaging applications, it is highly undesirable to have a pulse with long duration. Backing layer can be used to damp out the ringing by absorbing part of the energy from the vibration of the back face. Besides minimizing the acoustic impedance mismatch, the backing layer can also act as a supporting layer of the fragile transducer element because of its relative rigid nature of the piezoelectric layer.
The general schema of the ultrasonic level measurement is explaining in figure 2.5.

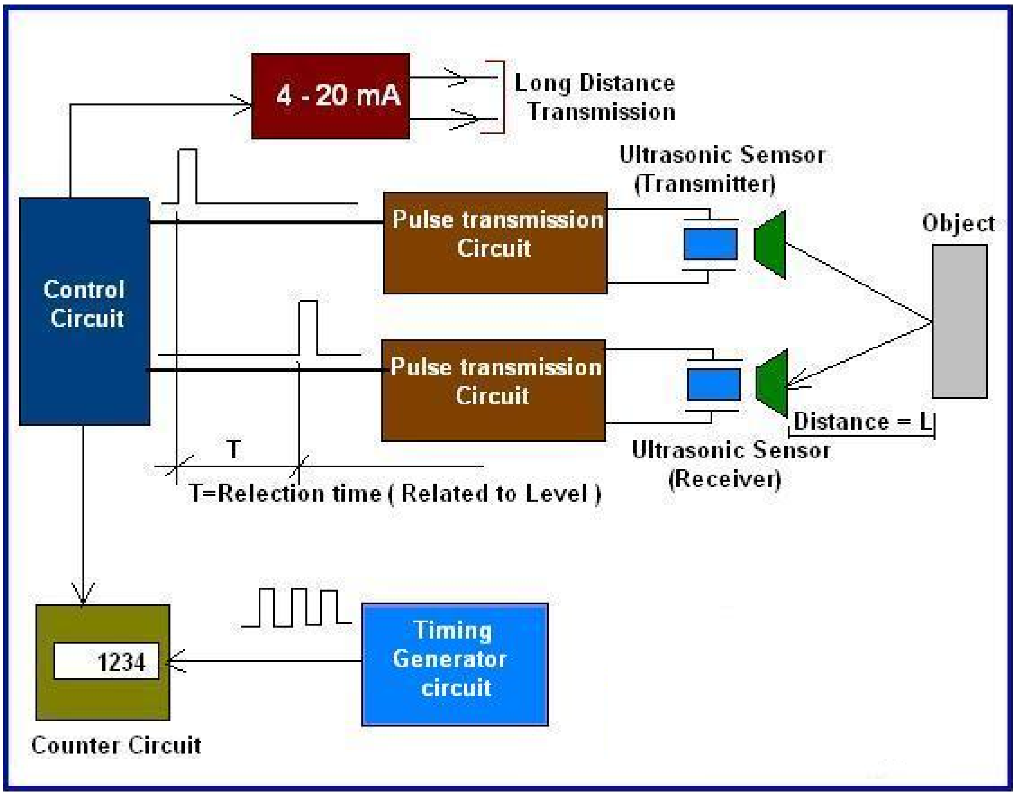


Figure 2.5: General schema of ultrasonic level measurement principle [10].

The module offers a suitable modulation with a frequency of 40 kHz in order to obtain an ultrasonic modulated signal from a pulse input upcoming from a pulse generator through the trigger input. In return, the ultrasonic signal is demodulated to be delivered through the echo output to the processor.

B Timing diagram

The Timing diagram is shown in figure 2.6. We only need to supply a short 10uS pulse to the trigger input to start the ranging, and then the module will send out an 8 cycle burst of ultrasound at 40 kHz and raise its echo. The echo is a distance object that is pulse width and the range in proportion. You can calculate the range through the time interval between sending trigger signal and receiving echo signal. Formula: $\frac{us}{58} = centimeters$ or $\frac{us}{148} = inches$ or the $Range =$ high level time $* \frac{velocity(340\frac{m}{s})}{2}$, we suggest to use over 60ms measurement cycle, in order to prevent trigger signal to the echo signal.

This module is implemented and placed easily thanks to its small dimensions and optimal form. The transmitter and the receiver are separated and this may form the only

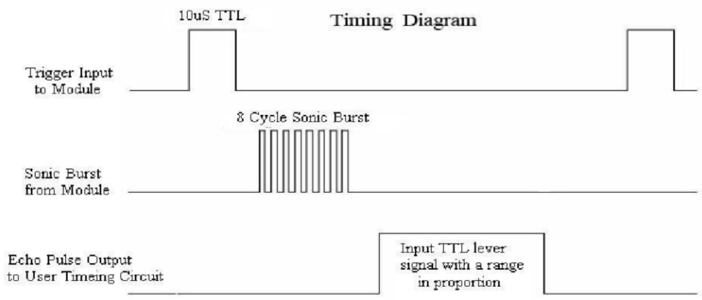


Figure 2.6: Timing diagram[26]

inconvenient to this module in some applications, but its very low price makes it the best choice for our project.

2.2 Pressure sensor

Pressure is a very common phenomenon in our daily life, it has effect on our bodies and environment in a necessary way. The importance of measuring pressure comes from its impact on all physical forms (gases, liquids and solids).

Moreover, in hydraulics engineering, process engineering, scientific researches such as medicine and biology and many other scientific fields, pressure measurement has to be taken with a reliable sensibility and strict precision due to the main position that it takes between the most important influencing factors.

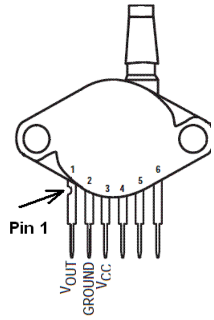
2.2.1 Pressure measurement in hydraulics

As mentioned before, pressure finds a place everywhere around us, but in hydraulics pressure gets the lion's share of importance thanks to the global view that it gives about the fluid in focus. Pressure measurement gives accessibility to many necessary other measurements in hydraulics such as the volume, temperature and fluid velocity. Almost every describing equation in hydraulics contains pressure value. Equation 2.4 represents the velocity V wrote in function of the dynamic pressure q.

$$V = \sqrt{\frac{2q}{\rho}} \tag{2.4}$$

Many existing methods and instruments take place nowadays as solutions to measure pressure in hydraulics. The most famous methods are certainly the mechanical methods and instruments such as the U pipe (to measure a differential pressure) and the barometer. These classical methods have relatively low prices but their reliability and precision is quite weak. However, the electronic sensors remain the best in that field with a sufficient precision and a good reliability. For example, the MPX4250AP pressure sensor of Motorola has a very good quality-price ratio and many good characteristics that led us directly to choose it (see figure 2.7).

(a) MPX4250AP picture



(b) MPX4250AP PINs

Figure 2.7: Motorola MPX4250AP pressure sensor.

2.2.2 Properties of the MPX4250AP

The MPX4250 series sensor integrates on–chip, bipolar op-amp circuitry and thin film resistor networks to provide a high level analog output signal and temperature compensation. The small form factor and reliability of on–chip integration make the Motorola MAP sensor a logical and economical choice for automotive system designers[27].

This sensor's working principle is very simple: when it is put to a pressure it directly gives an equivalent voltage that can be received from V_{out} PIN. In fact, this sensor works on the absolute pressure principle which is referred to the vacuum of free space (zero pressure). In practice, absolute piezoresistive pressure sensors measure the pressure relative to a high vacuum reference sealed behind its sensing diaphragm. The vacuum has to be negligible compared to the pressure to be measured. First Sensor's absolute pressure sensors offer ranges from 1 bar or even 700 mbar as well as barometric pressure ranges (see figure 2.8).

The different operating characteristics of this sensor are shown later in Appendix 1.2.

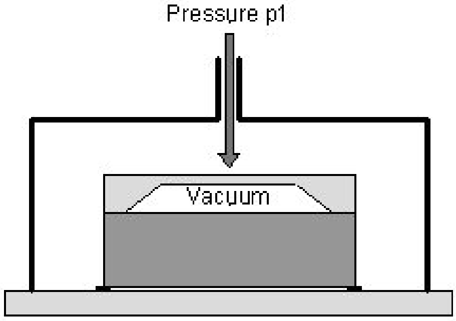


Figure 2.8: Principle of an absolute pressure sensor (piezoresistive technology) [28]

Its transfer function is given by:

$$V_{out} = V_s(P \cdot 0.004 - 0.04) \tag{2.5}$$

with $V_s = 5.1 \pm 0.25V$.

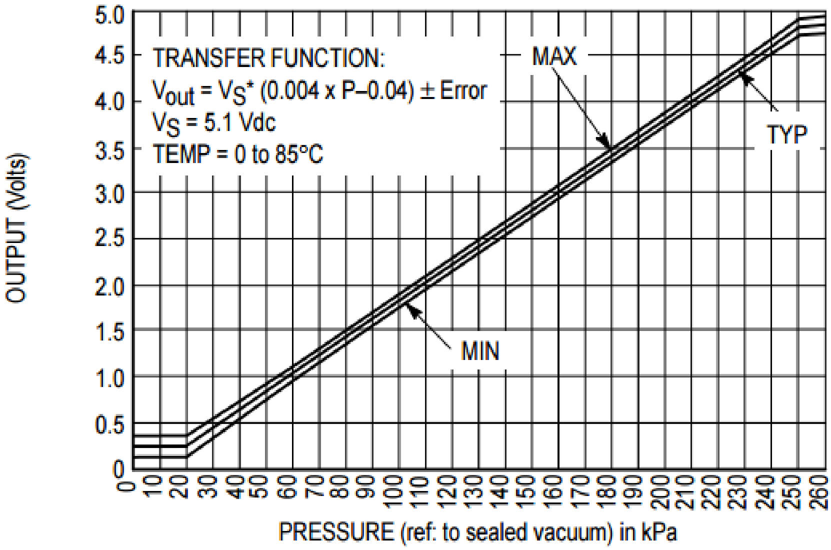


Figure 2.9: Output voltage in function of absolute pressure [27].

2.3 Microcontroller

The Microcontroller is a minimal system consisting of a microprocessor, memory and input/output interfaces.

2.3.1 Architecture of Microcontrollers

The architecture of a typical microcontroller is complex and may include the following [29]:

- A CPU, ranging from simple 4-bit to complex 64-bit processors.
- Peripherals such as timers, event counters and watchdog.
- RAM (volatile memory) for data storage. The data is stored in the form of registers, and the general-purpose registers store information that interacts with the arithmetic logical unit (ALU).
- ROM, EPROM, EEPROM or flash memory for program and operating parameter storage.
- Programming capabilities.
- Serial input/output such as serial ports.
- A clock generator for resonator, quartz timing crystal or RC circuit.
- Analog to digital converters.
- Serial ports.
- Data bus to carry information.

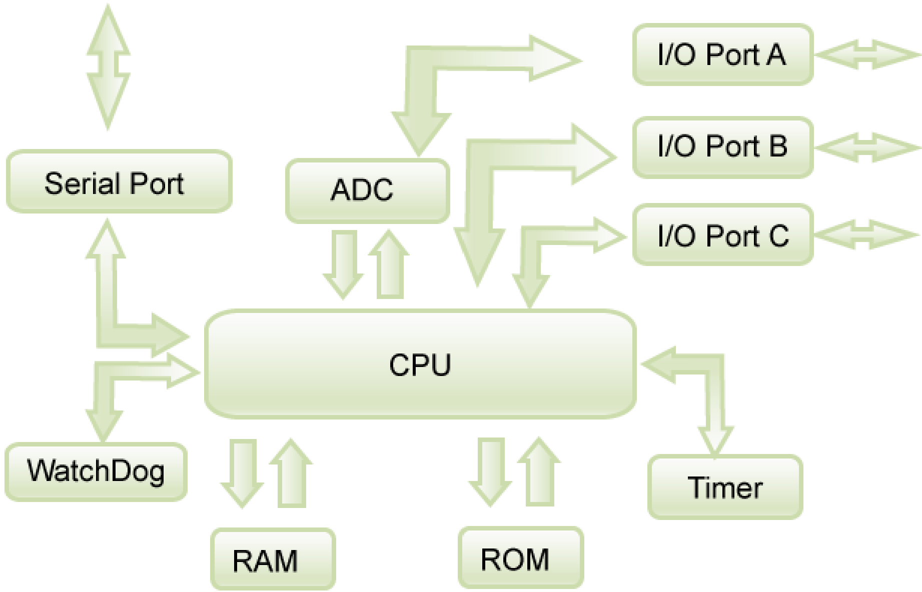


Figure 2.10: Typical architecture of a Microcontroller [29]

2.3.2 Classifications of Microcontrollers

Microcontrollers are characterized regarding bus-width, instruction set, and memory structure. For the same family, there may be different forms with different sources. We are going to describe some of the basic types of the Microcontroller.

A According to Number of Bits

Microcontrollers are classified to 8-bits, 16-bits and 32-bits microcontrollers.

- In 8-bit microcontroller (internal bus is 8-bit) performs the arithmetic and logic operations. The examples of 8-bit microcontrollers are Intel 8031/8051, PIC1x and Motorola MC68HC11 families.

- The 16-bit microcontroller performs greater precision and performance as compared to 8-bit. For example 8 bit microcontrollers can only use 8 bits, resulting in a final range of 0x00 – 0xFF (0-255) for every cycle. In contrast, 16 bit microcontrollers with its 16 bit data width has a range of 0x0000 – 0xFFFF (0-65535) for every cycle. A longer timer most extreme worth can likely prove to be useful in certain applications and circuits. It can automatically operate on two 16 bit numbers. Some examples of 16-bit microcontroller are 16-bit MCUs are extended 8051XA, PIC2x, Intel 8096 and Motorola MC68HC12 families.

- The 32-bit microcontroller uses the 32-bit instructions to perform the arithmetic and logic operations. These are used in automatically controlled devices including implantable medical devices, engine control systems, office machines, appliances and other types of embedded systems. Some examples are Intel/Atmel 251 family, PIC3x.

B According to Memory Devices

- *Embedded memory microcontroller:* when an embedded system has a microcontroller unit that has all the functional blocks available on a chip is called an embedded microcontroller. For example, 8051 having program and data memory, I/O ports, serial communication, counters and timers and interrupts on the chip is an embedded microcontroller.

- *External Memory Microcontroller:* when an embedded system has a microcontroller unit that has not all the functional blocks available on a chip is called an external memory microcontroller. For example, 8031 has no program memory on the chip is an external memory microcontroller.

C According to Instruction Set

- *CISC:* stands for Complex Instruction Set Computer. It is a computer where single instructions can execute several low-level operations (such as a load from memory, an arithmetic operation, and a memory store) or are capable of multi-step operations or addressing modes within single instructions, as its name suggest "COMPLEX INSTRUCTION SET".

- *RISC:* stands for Reduced Instruction Set Computer. It is a computer which only use simple instructions that can be divide into multiple instructions which perform low-level operation within single clock cycle, as its name suggest "REDUCED INSTRUCTION SET".

D According to Memory Architecture

- *Harvard Memory Architecture :* the point when a microcontroller unit has a dissimilar memory address space for the program and data memory, the microcontroller has Harvard memory architecture in the processor.

- *Von Neumann Memory Architecture:* the point when a microcontroller has a common memory address for the program memory and data memory, the microcontroller has Von Neumann memory architecture in the processor.

2.3.3 The Microcontroller PIC18F2550

PIC (Peripheral Interface Controller) microcontrollers are made by Microchip Technology, their architecture is a modified Harvard architecture.The PIC family is characterized by a separate code and data spaces (Harvard architecture) and a small number of fixed-length instructions. PIC microcontrollers are widely used thanks to their very low price, easy implementation, small dimensions and their high availability in markets.

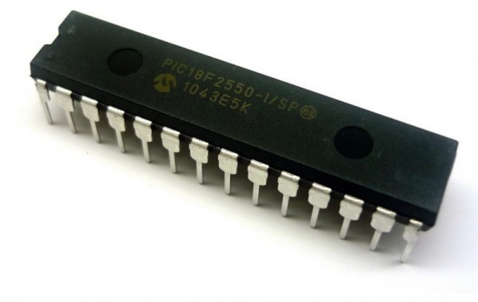


Figure 2.11: Microcontroller PIC18F2550 [30].

Technically, we have judged PIC18F2550 as the best choice due to the satisfaction that it gives to all needs in our project. We give below some of the main reasons that led us to that choice in a form of properties and advantages that this microcontroller disposes.

The different pins of the PIC18F2550 are shown in figure 2.12, the pins are what stick out of an IC, and connect electrically to the outside world. Ports are represented by registers inside the microcontroller, and allow the program to control the state of the pins, or conversely, read the state of the pins if they are configured as inputs. There is a one-to-one correspondence between the pins on the microcontroller and the bits in its registers.

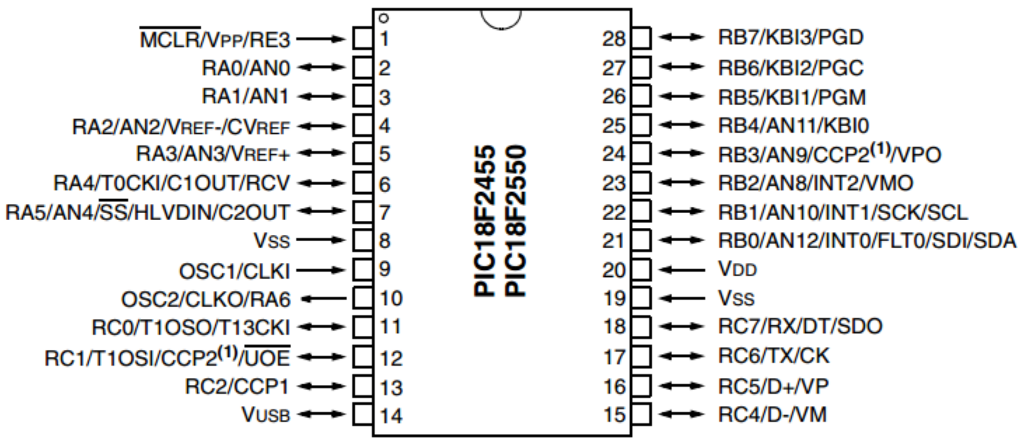


Figure 2.12: PIN definition of PIC18f2550 [31].

You find all properties of the Microcontroller PIC18F2550 below in the appendix 1.3 with all details for its different parts.

2.4 Serial communication

Serial communication is a method of transmitting data between a computer and a peripheral device such as a programmable instrument (microcontroller for example) or another computer. Serial communication transmits data one bit at a time, sequentially, over a single communication line to a receiver. Serial is also a most popular communication protocol that is used by many devices for instrumentation. This method is used when data transfer rates are very low or the data must be transferred over long distances and also where the cost of cable and synchronization difficulties make parallel communication impractical. Serial communication is popular because most computers have one or more serial ports, so no extra hardware is needed other than a cable to connect the instrument to the computer or two computers together.

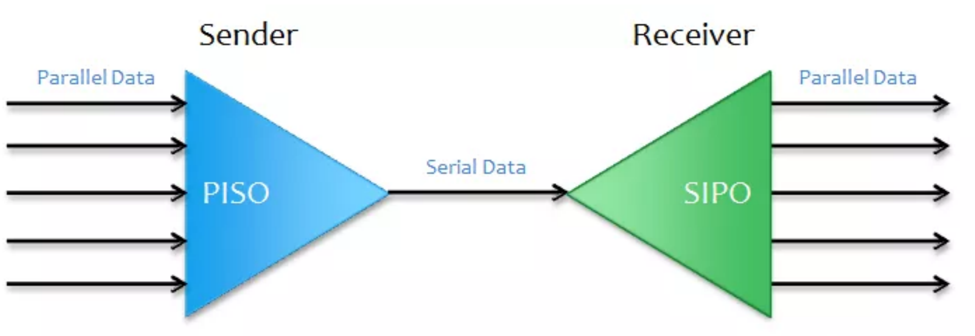


Figure 2.13: Serial transmission of parallel data [32].

2.4.1 Serial Communication and Parallel Communication

We know that parallel ports are typically used to connect a PC to a printer and are rarely used for other connections. A parallel port sends and receives data eight bits at a time over eight separate wires or lines. This allows data to be transferred very quickly. However, the setup looks more bulky because of the number of individual wires it must contain. But, in the case of a serial communication, as stated earlier, a serial port sends and receives data, one bit at a time over one wire. While it takes eight times as long to transfer each byte of data this way, only a few wires are required. Although this is slower than parallel communication, which allows the transmission of an entire byte at once, it is simpler and can be used over longer distances. For example, the IEEE 488 specifications for parallel communication state that the cabling between equipment can be no more than 20 meters total, with no more than 2 meters between any two devices; serial, however, can extend as much as 1200 meters (with high-quality cable). So, at first sight it would seem that a serial link must be inferior to a parallel one, because it can transmit less data on each clock tick. However, it is often the case that, in modern technology, serial links can be clocked considerably faster than parallel links, and achieve a higher data rate. Even in shorter distance communications, serial computer buses are becoming more common because of a tipping point where the disadvantages of parallel buses (clock skew, interconnect density) outweigh their advantage of simplicity (no need for serializer and deserializer). The serial port on your PC is a full-duplex device meaning that it can send and receive data at the same time. In order to be able to do this, it uses separate lines for transmitting and receiving data (figure 2.14).

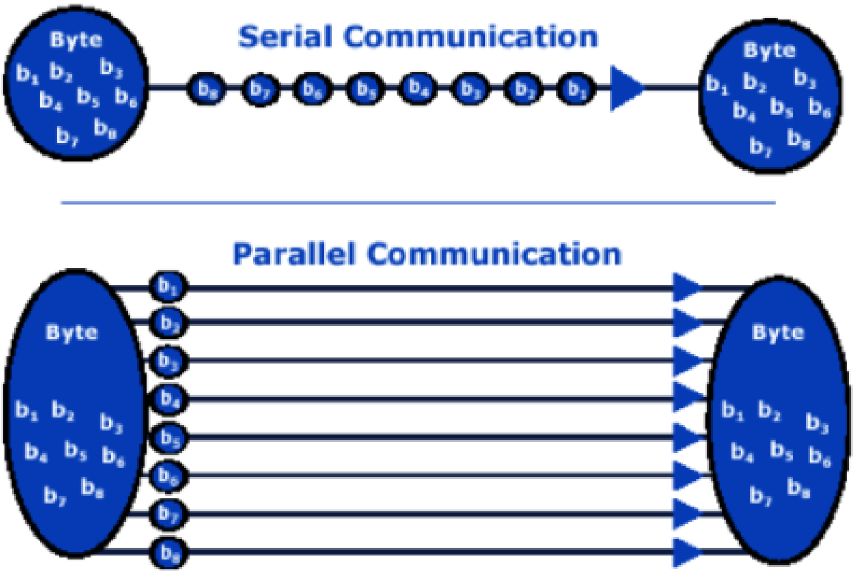


Figure 2.14: Serial and parallel transmission [32].

Here we summarize the comparison between serial and parallel communication:

Serial Communication	Parallel Communication
One data bit is transmitted at a time	Multiple data transmitted at a time
Slower	Faster
Less number of cables required	Higher number of cables required

Table 2.1: Serial and parallel communication.

Now we can conclude the advantages that leads us to chose the serial communication over the parallel communication:

- Requires fewer interconnecting cables and hence occupies less space.
- Cross talk is less of an issue, because there are fewer conductors compared to that of parallel communication cables
- Many ICs and peripheral devices have serial interfaces
- Clock skew between different channels is not an issue
- No need of SerDes (Serializer/Deserializer)
- Cheaper to implement

2.4.2 Serial communication standards

The most known standards of serial communications are RS-232 and USB, they are applied in many devices that we use daily such as the personal computers and televisions. These two standards are of a very high performance. We expose below the main characteristics of these two standards.

A RS-232

Before Universal Serial Bus (USB) in computers RS232 was used as a standard port for communication between different devices like printers, mouse, modems and all other type of computer peripherals and the computer. In terms of definition, RS232 can be defined as point to point communication between the Data Terminal Equipment (DTE) and Data Communication Equipment (DCE). On RS 232, 920 Kbps of data speed is achievable and the fact that it is called a serial port is that it transfers data bit by bit. RS232 comes in two different variants of D-style 9 pin and 25 pin the former is called as DB 9 connector and the later is called as DB 25 connector, however only three pins are required for communication.

Figure 2.15: RS-232 cable.

Other pins present in RS 232 port are used depending upon the peripheral support. Devices like Modem utilize all the pins to achieve full handshaking capabilities. For having reliable communication, the length of cable used should be less than 15 meters. set to 9600 baud rate. To have a communication over long distance, other resources like wireless communication can also be used. Before 1997 the RS232 was termed as EIA232F, where EIA stands for "Electronic Industries Association" were it was developed but after the renewal of standards its name was replaced with RS232.

The PINs description as it used in DB9 connector is shown in figure 2.16. For more details please check Appendix 1.4.

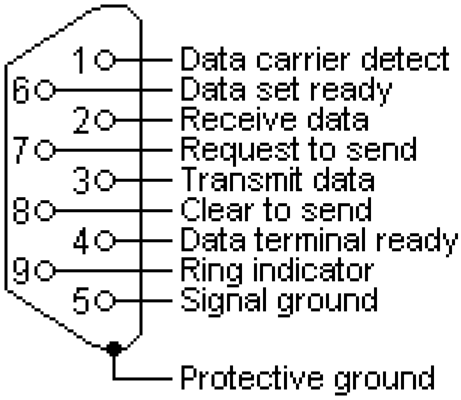


Figure 2.16: Pin description in RS-232 [29].

B Universal Serial Bus - USB

From an outer overview, USB has two components: cables and connectors. These connectors connect devices to a host. A USB cable consists of multiple components that are shielded by an insulating jacket. Underneath the jacket is an outer shield that contains a copper braid. Inside the outer shield are multiple wires: a copper drain wire which is a twisted pair of cable, a VBUS wire (red) and a ground wire (black). An inner shield made of aluminum contains a twisted pair of data wires, figure 2.17 shows the different types of USB connector.

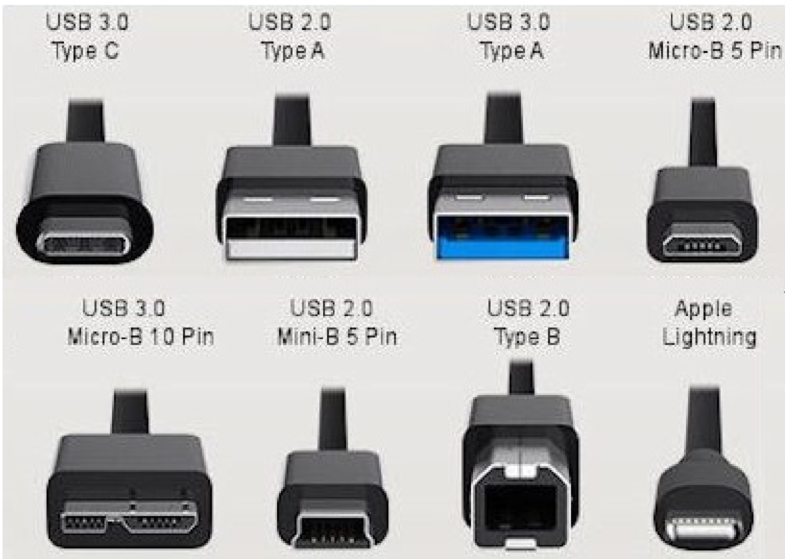


Figure 2.17: USB types.

There is a D+ wire (green) and a D- wire (white). In full-speed and high-speed devices, the maximum cable length is 5-meters. To increase the distance between the host and a device, you must use a series of hubs and 5-meter cables. While USB extension cables exist in the market, using them to exceed 5 meters is against the USB specification. Low-speed devices have slightly different specifications. Their cable length is limited to 3 meters and low-speed cables are not required to be a twisted pair as USB Twisted Pair Data Wires. The voltage bus gives a constant 4.40 v – 5.25v supply to all devices and the data lines supplies up to 3.3v. The reason for using the differential D+ and D- signal is for rejecting common-mode noise. If noise becomes coupled into the cable, it will normally be present on all wires in the cable. With the use of a differential amplifier in the USB hardware internal to the host and device, the common mode noise can be rejected.

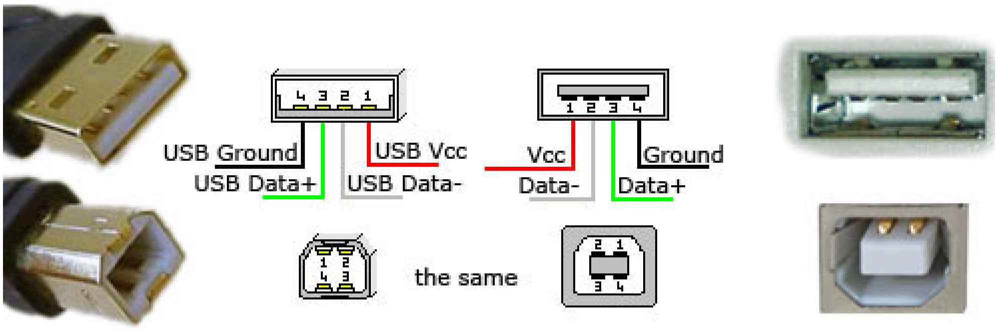


Figure 2.18: Pin description in USB (Type A and B) [33].

The USB PINout:

PIN	Name	Cable color	Description
1	VCC	Red	+5 VDC
2	D-	White	Data -
3	D+	Green	Data +
4	GND	Black	Ground

Table 2.2: USB pin description

Advantages of the USB :

- Higher Speed: USB runs at up to 12Mbit/second; that's 12,000,000 bps (bits per second). Traditional serial ports mostly run at up to 115200 bps and even then can be subject to data loss due to UART overflows and missed interrupts. USB has none of those problems - speed is reliable and high.
- Multiple Devices: A USB port can run many devices at once, up to 128 in total. To add more devices to a single port, a low cost hub (splitter) can be used. Hubs are often built into monitors. The great advantage is that you no longer have to worry about having enough ports for new peripherals or use ports for purposes for which they weren't intended (e.g. external tape drives on parallel ports !).
- Self-Powered: USB provides power to the peripherals you connect, so there is no need for an external mains PSU for most products.
- Truly Plug & Play: USB devices configure themselves; your PC will automatically detect the new device and install the software for it.
- Hot-Swappable: USB devices can also be hot-swapped - i.e. connected or removed while the PC is switched on.

2.4.3 USB Human Interface Device Class

Many special characteristics are major for computers to recognize the type of the devices that are connected.therefore, many classes have been specified in order to organise the recognition and make it easier to effect.

Human interface device (HID) is a computer peripheral that interacts directly with human beings either as an input or an output. If we take, as examples, the devices we use daily to interact with the computer, the inputs will be : mouse, keyboard, web-cam and microphone, whereas the outputs will be : the monitor, headsets, loudspeakers, etc.

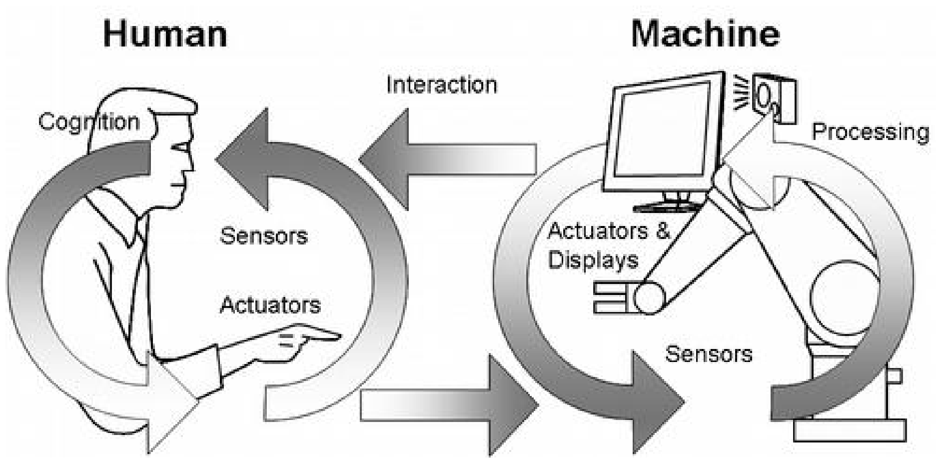


Figure 2.19: Human Intervention with machine [34]

USB-HID class is a specification that describes the devices connected the computer. This class offers real time data traffic in both directions (input and output), this characteristic makes USB-HID class very useful not only for daily peripherals but also for all devices that need real time data traffic such as the microcontrollers.
The property mentioned above allows us to send the data collected from different sensors and processed by the microcontroller to the computer in the interest of storing, plotting and analysing.

2.5 Graphical user interface (GUI)

When arriving to the computer, data has to be visualized, classified, processed and plotted. In order to accomplish this mission, the user needs to have access to data through a graphical interface that will organize the functions cited above and at the same time guide the user directly to the function he needs. In other words, the graphical interface is a layer between data and the user which will make the interaction easier.

We will define the graphical interface, to make the approach easier to the understanding, as a user's interface that includes graphical elements, such as windows, icons and buttons. The term was created in the 1970s to distinguish graphical interfaces from text-based ones, such as command line interfaces. However, today nearly all digital interfaces are GUIs.

Usually, the normal user of the computer interacts only with the graphical interfaces that the exploitation system offers (Microsoft Windows for example). Hence, the graphical interfaces are the most simplified way to interact with the different applications. For example, in order to have access to the world wide web, we use a browser such as "Google Chrome", "Windows Internet Explorer", "Mozilla FireFox",...

However, our data access is a particular function that needs to be organised with a specified graphical interface dedicated only for this function. Therefore, we proceeded in the creation of our own graphical interface using the tool offered by Microsoft and named Microsoft Visual Studio. This tool is very recommended and requires the use of a specific programming language which is C#. An example of our Graphic User Interface is shown in figure 2.20.

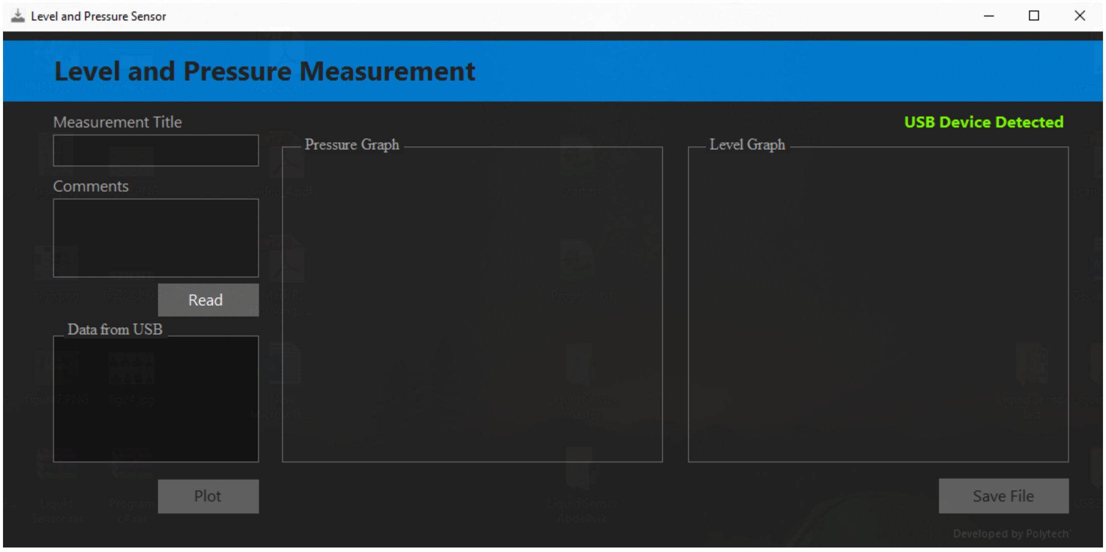


Figure 2.20: Graphic User Interface of Liquid Sensor.

2.6 Conclusion

After having chosen the suitable measuring methods, the conditioning of the measuring instruments is as important as the choice itself, bad conditioning can lead to wrong results and even the good choice would have no impact or efficiency. All the sensors used should be calibrated in order to give the real results in the experiments; the calibration is done using the equations given by the constructor of the sensors.

Chapter 3

Experiments and Results

3.1 Problem Formulation

Hydraulic systems' main problem is the measurement of certain parameters such as the pressure, level, velocity and fluid flow. The importance of these parameters comes out of the fact that hydraulic systems' studies relies essentially on the knowledge and the measurement of these important parameters. The lack of measuring methods impose many difficulties in lab works and scientific researches in this field. The few existing methods are mostly mechanical and thermal, which means greater time constants and slower systems that can't follow the fast variations. Furthermore, the lion's share of the existing methods is analog, removing any possibility of electronic processing and storage. All these problems have been slowing down the development in hydraulics and many other fields until the appearing of the electronic transducers.

3.1.1 System presentation

Our system is a test prototype for airlift pumps that inject compressed air in the bottom of a discharge pipe that transports a liquid. The liquid which is more dense than compressed air is lifted by ascendant air flow.

The test prototype consists of a water source (the tap) from which the water flows into a special small tank to maintain a constant pressure in the closed reservoir which is at the same altitude, an air compressor to inject compressed air into the reservoir, another small tank to visualise the 'J' form of water coming from the reservoir (pressure effect) and a big tank to receive the water and measure the flow (figure 3.1).

First, the water source flows water into the first tank which, independently of the source flow, maintains a constant pressure by keeping a constant water level and evacuating the excess, this is how the pressure at the closed reservoir is maintained constant. After that, the water pressure is increased by injecting compressed air coming of the air compressor. The water achieves the higher small tank thanks to the pressure applied by the compressor and it falls back down to form a 'J' letter. Finally, the water falls down to the big tank that keeps a constant level and evacuate the excess.

The study of this system has a goal to define and find a relation between the compressed air flow injected in the reservoir and the water flow out coming of it. It can be used in oil extraction : the reservoir - second tank part represents a petroleum oil well, the compressed air is injected to push the oil upwards to the surface.

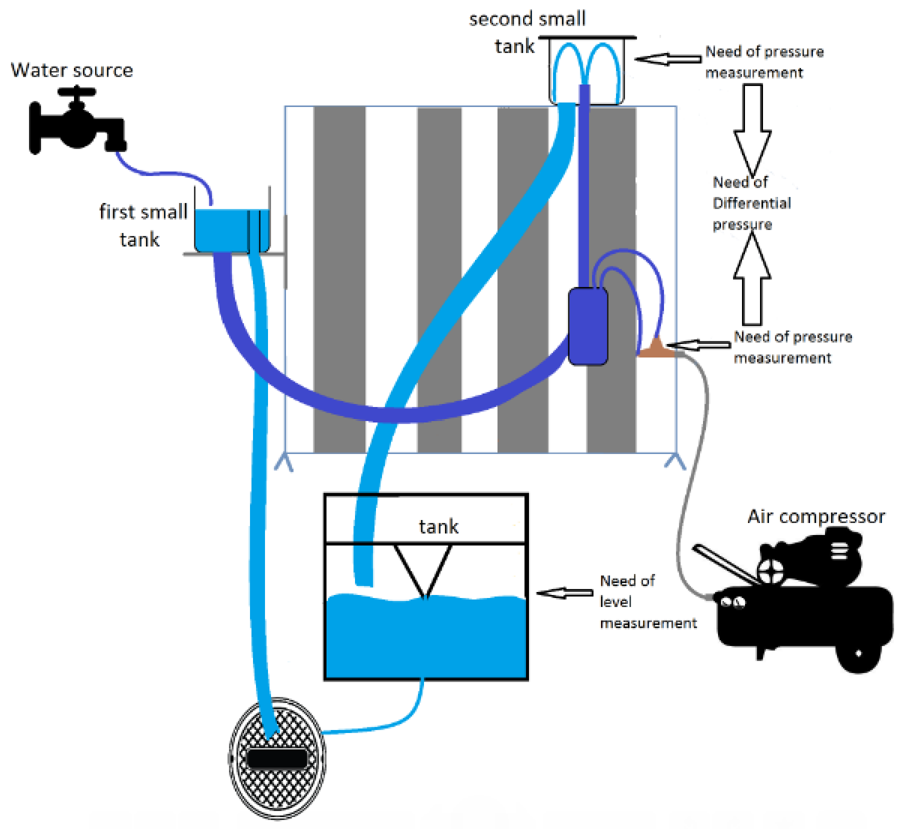


Figure 3.1: The hydraulic system

3.1.2 Previous solutions

Traditional solutions exist, such as the U tube manometer to measure the differential pressure and the ruler for the water level (see figure 3.2).

3.1.3 Problems and error calculation

These methods pose many difficulties and disadvantages, not only systematic errors such as precision and resolution, but also introduce the human stochastic errors when reading the analog measurement values.

A Resolution

The resolution of either the U tube manometer or the ruler depends directly on the smallest graduation of the ruler. Even with good imposed conditions, the best resolution may not always be reached because the resolution of the human eye is limited as well. We can calculate the resolution of the mercury U tube manometer knowing the density of mercury ($13.6g/cm^3$) for $\Delta h = 1mm$ difference of height as the smallest difference that can be clearly visualised by human eye and using the equation.

$$\Delta P = \rho g \Delta h \tag{3.1}$$

Replacing in the equation3.1 we find $\Delta P = 0.133\ kPa$ which represents the minimum difference value that can be measured using the U tube manometer. For the level

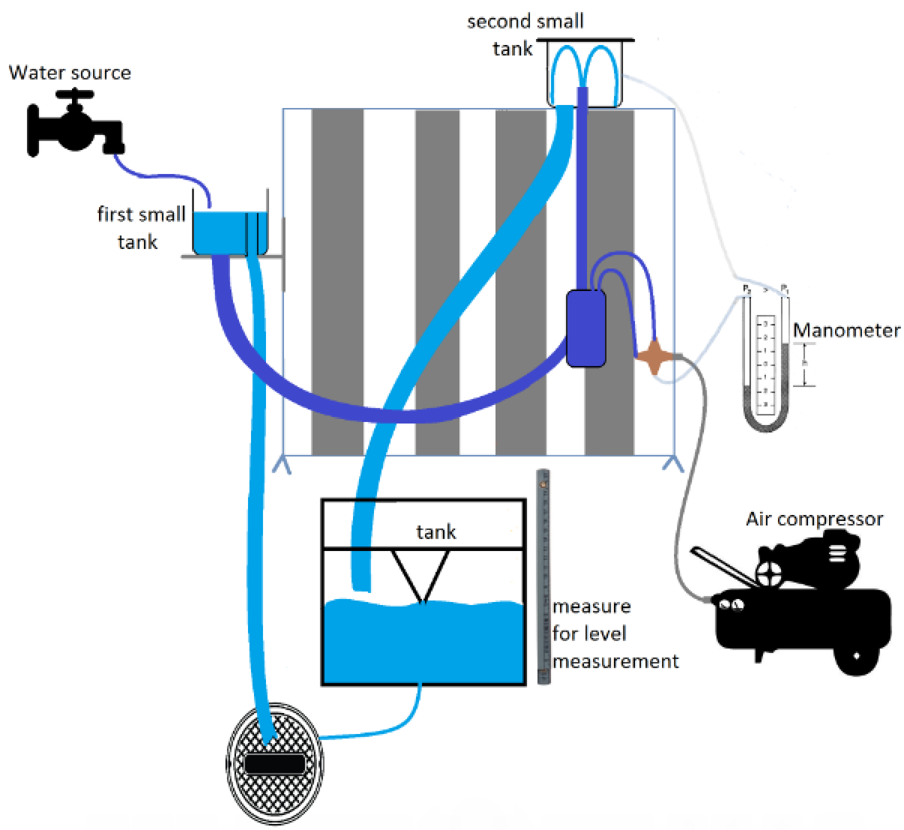


Figure 3.2: The hydraulic system with traditional measurement methods

measurement the resolution is obviously depending on the stability of the water surface but can be maximized by 1mm.

B Precision

The precision for the pressure measurement is related to the variable measuring conditions such as the temperature and humidity. Actually, the temperature is the most influencing parameter on mercury's density. The variation of the mercury's density (expressed in gram per cubic centimeters) with temperature (expressed in degree Celsius) is given by the equation 3.2.

$$\rho_m = 13.6 - 0.00246 \cdot T_m \tag{3.2}$$

Moreover, the disposition of the manometer compared to the horizontal and the vertical lines strongly affects the results and introduces errors estimated by centimeters in height which means kilo Pascals in pressure.

In addition, meniscus curve is formed due to the mercury-glass contact with an angle of 140 degrees. The meniscus curve affects the readability and introduce errors while measuring the mercury level.

C Stochastic errors

Above all types of errors, the human statistical errors cannot be compensated or precised like the systematic errors, they differ from one experience to another and from one person to the other. This type of error varies over a large range of values that should be evaluated and maximised in experimental conditions.

D Other problems

Rather than precision and resolution problems, this system needs a real-time follow and continuous measuring which are impossible using the U tube manometer because every taken value is a height difference that needs to be converted mathematically into a differential pressure. A bigger problem is the height that it needs to measure 250 kPa, it needs at least two meters in order to scan this range.

3.2 Proposed solution

In order to resolve the problems mentioned above, we have replaced the previous methods with more efficient electronic devices. The global principle of measurement is the same, but many advantages have been introduced using electronic measurement (see figure 3.3).

Our electronic system consists of a group of sensors sending out data to a microcontroller, this last processes the data and send it to the computer through a USB cable. The data is then registered and plotted.

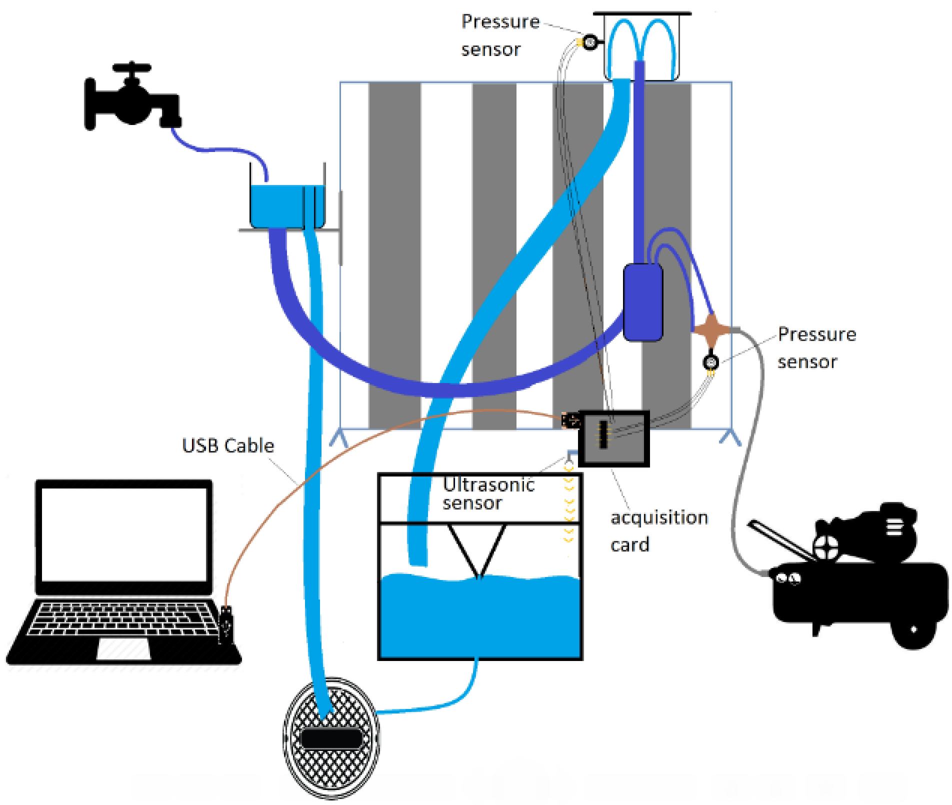


Figure 3.3: The hydraulic system with the new measurement methods

3.2.1 Devices used

- One ultrasonic transceiver HC-SR04 for level measurement in the big tank.
- Two Pressure sensors Motorola MPX4250AP for air pressure measurement in two points: the compressed air coming from the air compressor and the air pressure in the second small tank.
- One Microcontroller PIC18F2550 for data acquisition, processing and sending out to the computer.
- One USB port and one USB cable for the serial communication between the microcontroller and the computer.

The microcontroller represents the data center of our system, all data coming out from the sensor and ingoing to the computer is processed by the microcontroller.

3.2.2 PIC Program

The data acquisition and processing is defined by a program that will be executed by the microcontroller, this program is written in C language and compiled using the Mikroelectronika "MikroC" compiler.
You find the full PIC program in appendix 2.1.

Brief explanation of the program

This program contains 3 main parts :

- PIN instantiation and definition
- Variable declaration
- Processing instructions and function calling

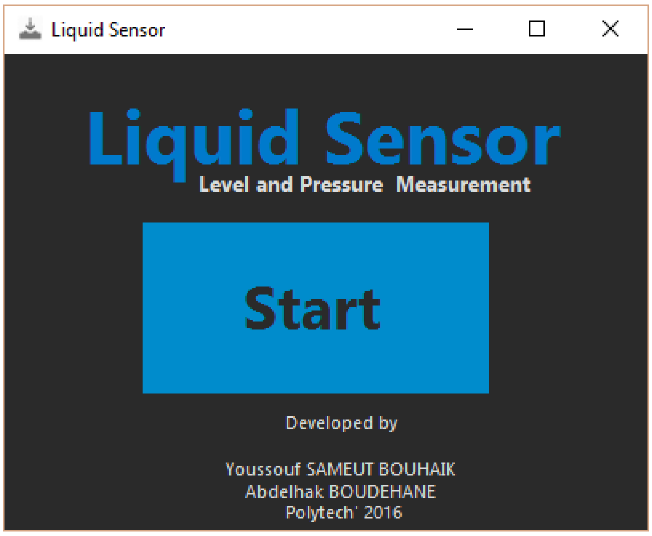
The PIN instantiation relates the internal variables to the external PINs. The external PINs can be defined as input or output PINs according to the need.
The variable declaration is to define the type and the size of each variable in order to limit the memory space allocation.
The function calling is to use a predefined functions, that can be found in libraries, in the program to realise a processing purpose.

The first part of the program is about the output PIN instantiation with the LCD screen PINs in order to manage the display. The second part declares the variables used in the program: long float variables for analog data acquisition, integer variables for digital data and counters and character tables for the display of data (ASCII code). The third part is the data processing that includes two sub-parts : one is for microcontroller registers definition, it means the specification of the parameters used and their functions, ex: the specification of the timer initial value. The other one is for the arithmetic processing like the distance calculation from the delay between the pulse sending and reception.

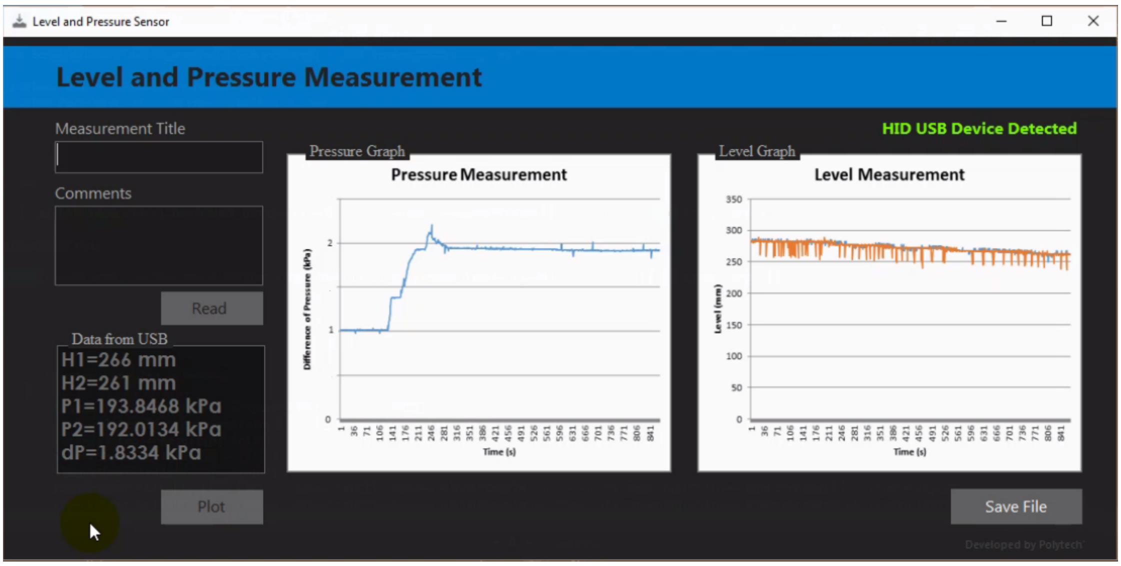
3.2.3 Graphic User Interface

Graphic User Interface (GUI) is a software interface that allows users to interact with electronic devices through graphical and visual indicators such as icons, buttons, textboxes, etc, which require commands to be typed on the keyboard and mouse.

In our project we have developed a specific graphic interface in order to help users controlling the system operation and performance, and read and manipulate the sensors outputs in order to compare, plot, save the resulting data.
This interface was developed using C# language benefiting from the huge amount of options and tools that *Visual Studio 2015* platform affords. General overview of the two forms of our Graphic Interface is shown in figures 3.4a and 3.4b.



(a) Graphic User Interface start form.



(b) Graphic User Interface main form.

Figure 3.4: Graphic User Interface of Liquid Sensor.

3.2.4 GUI Program

The full interface program explaining all the interface parts is shown in Appendix 2.2. The program is written using C# language using Visual Studio 2015.

Brief explanation of the program In the interface we have used the USB-HID library to read and write via USB, a simple button to read data and write them in a display box which shows level and pressure sensors outputs.
The interface also has two graph boxes and a "Plot" button to plot the level values and the difference of pressure against time in seconds.
All the data received are written in an Excel file created when the application starts, and saved using a "Save" button. Level and pressure graphs are exported from the Excel file and imported to the picture boxes in the graphic interfaces.

3.2.5 Simulation

We have simulated the functioning of the sensors and the microcontroller using *Proteus 8 Professional*. We have made sure of the data receiving and processing by the microcontroller using an LCD screen for display.

We have displayed the pressure sensors values in figure 3.5 while the ultrasonic transceiver values are displayed in figure 3.6.

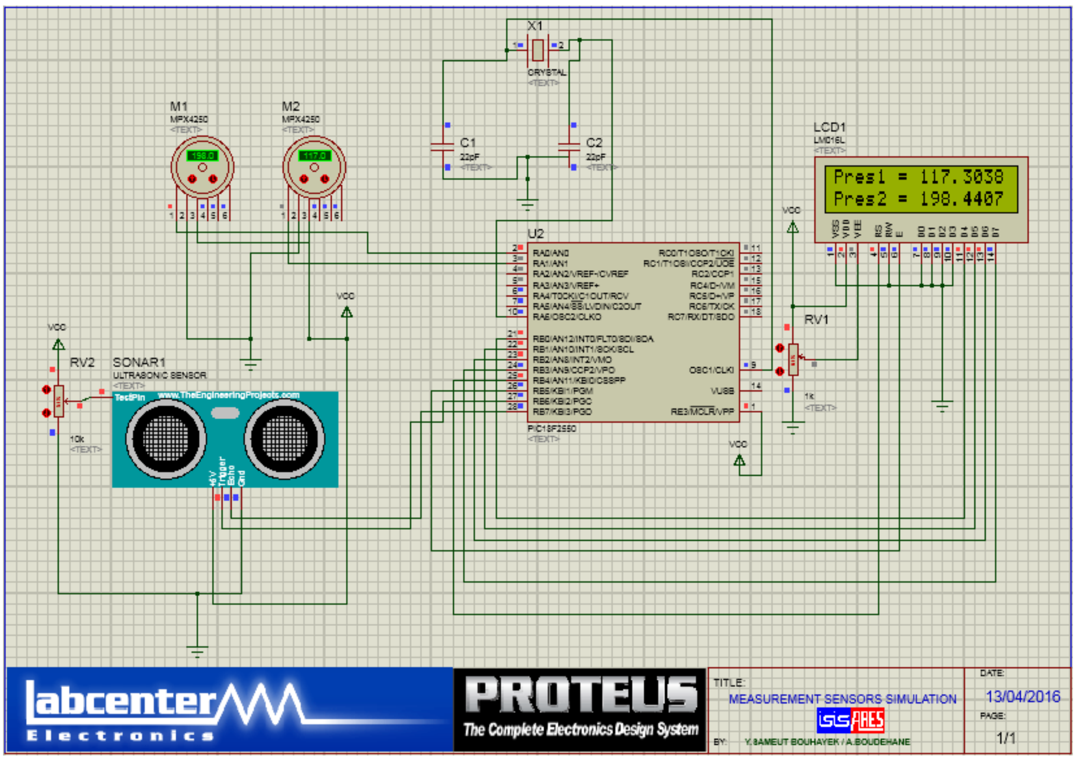


Figure 3.5: Pressure simulation using Proteus.

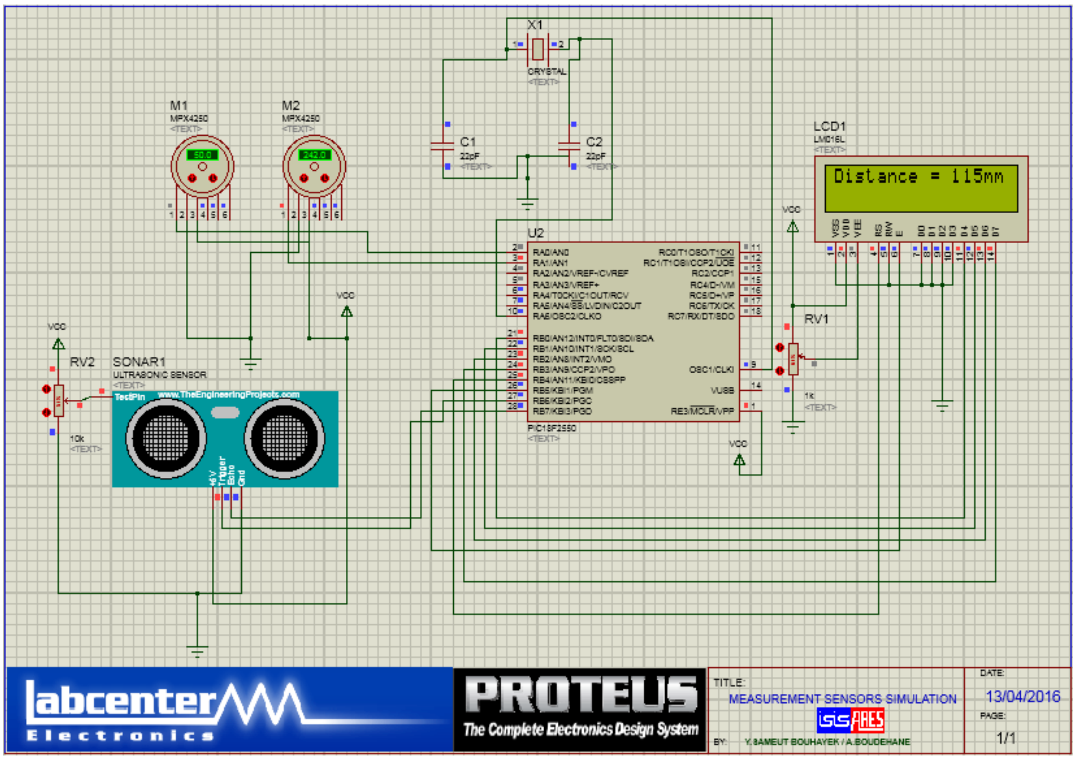


Figure 3.6: Ultrasonic simulation using Proteus.

As we see, the LCD displays the values of the pressure sensors which means that the data processing is working perfectly with variations.
For the ultrasonic module, Proteus gives us the possibility to simulate it without an obstacle, it offers an additional PIN dedicated to receive variable voltage from a potentiometer. It is also displayed on LCD.

Actually, the simulation part is very important as a first step, but it needs a practical verification in order to test the functioning of the measuring system in the real physical conditions on the real parameters.

3.2.6 Experiments

We fixed the pressure sensors on the points where we need to measure pressure, and we fix the ultrasonic transceiver within the acquisition card on the big tank. We linked the card with a USB cable to the computer and we began visualizing the measurement through the graphic interface and the barometer of the air compressor.
The whole circuit, the different sensors and the whole hydraulic system is shown in figures 3.7, 3.8, 3.9

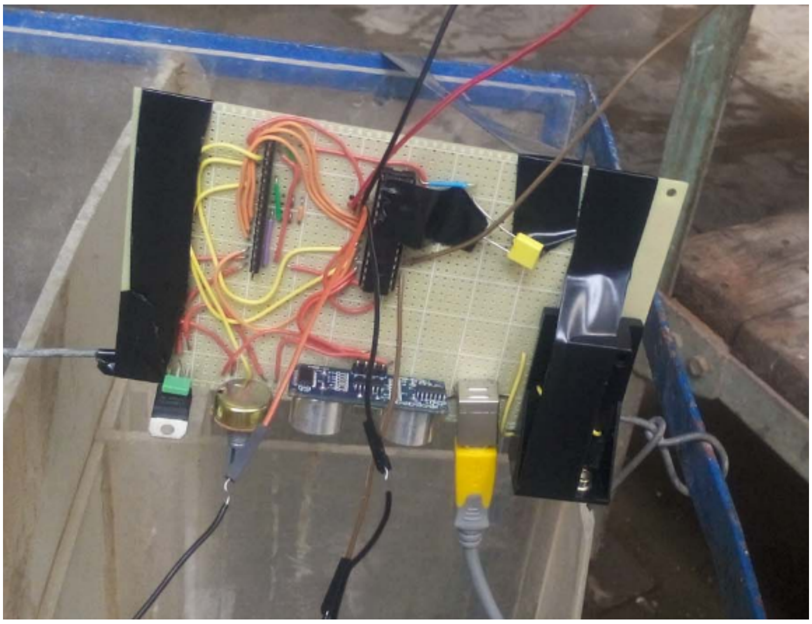


Figure 3.7: The acquisition card with the ultrasonic sensor below

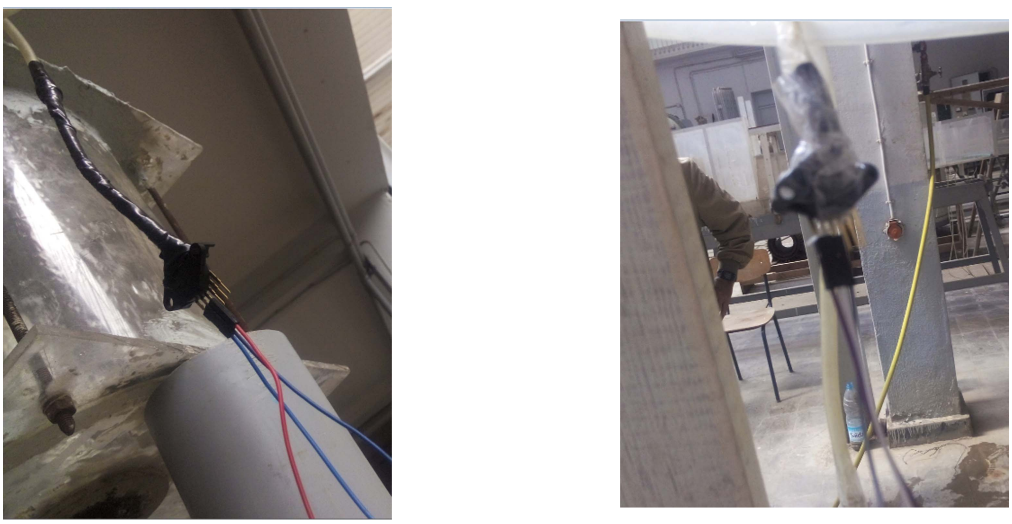


Figure 3.8: Pressure sensors

(a) front view (b) side view

Figure 3.9: Global view of the system

A Test One

During this test the pressure out of the air compressor was around 120 kPa. The water level was around 280 mm.

We have been able to follow, in real-time, the small variations of pressure and level. At the same time, we have been following the pressure value indicated on the air compressor barometer. Comparing the values indicated on the interface and the air compressor barometer, no difference can be found (see figure 3.10).

(a) pressure on the compressor barometer. (b) pressure values coming from the sensor.

Figure 3.10: pressure values

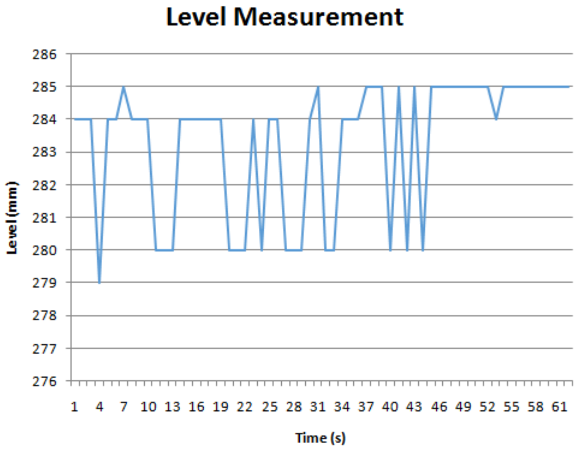
We have registered the values in excel file and plotted the graphs in order to visualize the evolution of the pressure and the level as while as visualising the continuous pursuing of the changing values by the sensors. We can see the values tables in table 3.1.

Time (s)	Level (mm)	P1 (kPa)	P2 (kPa)	P2-P1(kPa)
1	284	102.9286	124.1685	21.2399
2	284	101.2514	122.9706	21.7192
3	284	102.9286	123.4498	20.5212
4	279	103.8869	123.4498	19.5629
5	284	102.4494	122.2518	19.8024
6	284	102.9286	122.4914	19.5628
7	285	102.689	122.731	20.042
8	284	101.9702	122.9706	21.0004
9	284	102.689	122.731	20.042
10	284	102.9286	122.731	19.8024
11	280	101.491	122.0122	20.5212
12	280	103.6473	122.9706	19.3233
13	280	102.689	122.731	20.042
14	284	102.2098	122.0122	19.8024
15	284	103.1681	123.2102	20.0421
16	284	102.689	122.731	20.042
17	284	103.1681	122.4914	19.3233
18	284	103.8869	122.0122	18.1253
19	284	102.2098	121.2935	19.0837
20	280	103.1681	122.0122	18.8441
21	280	103.6473	122.9706	19.3233
22	280	102.9286	122.0122	19.0836
23	284	103.1681	121.5331	18.365
24	280	103.4077	120.8143	17.4066
25	284	101.7306	122.0122	20.2816
26	284	103.1681	121.5331	18.365
27	280	102.4494	121.0539	18.6045
28	280	103.1681	122.9706	19.8025
29	280	102.9286	122.2518	19.3232
30	284	103.4077	122.731	19.3233
31	285	102.2098	121.0539	18.8441
32	280	102.2098	122.4914	20.2816
33	280	103.1681	121.7726	18.6045
34	284	101.491	121.5331	20.0421
35	284	103.1681	123.2102	20.0421
36	284	103.1681	121.7726	18.6045
37	285	101.9702	122.4914	20.5212
38	285	101.7306	120.3351	18.6045
39	285	102.4494	120.8143	18.3649
40	280	101.7306	119.6164	17.8858

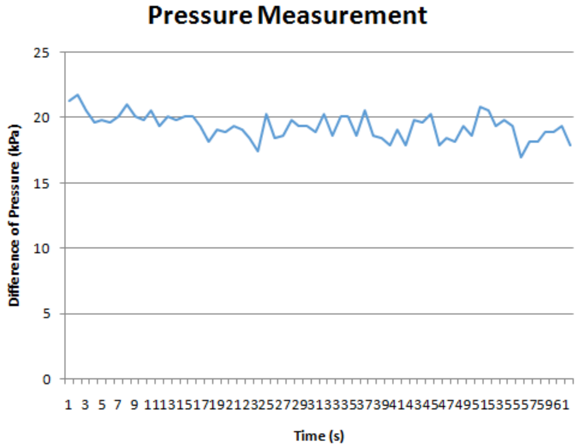
Table 3.1: Test One: table of values

The first column shows the timing of the data receiving (second), the second shows the level measurement (mm), the third and the fourth columns show the pressure measurement coming from the two pressure sensors and the last column shows the differential pressure (dynamic pressure) between the first and the second sensor.

However, a better analysis can be deducted when visualising the plots of level and differential pressure, therefore, we have attached the values table with the graphs 3.11.



(a) Level



(b) Differential pressure

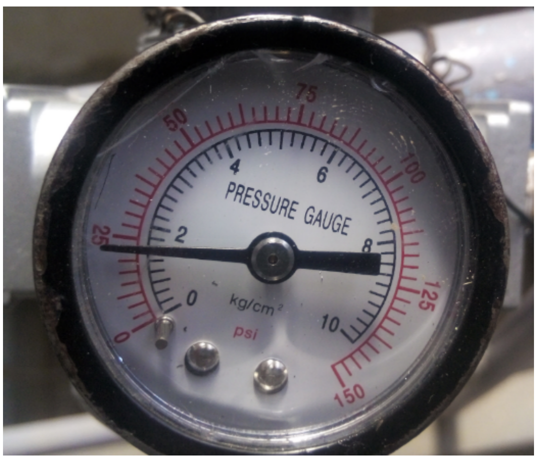
Figure 3.11: Test One : graphics

we can visualize that both graphics are oscillating around average values because our system is maintained stable by keeping the compressor at a fixed value (around 120 kPa).

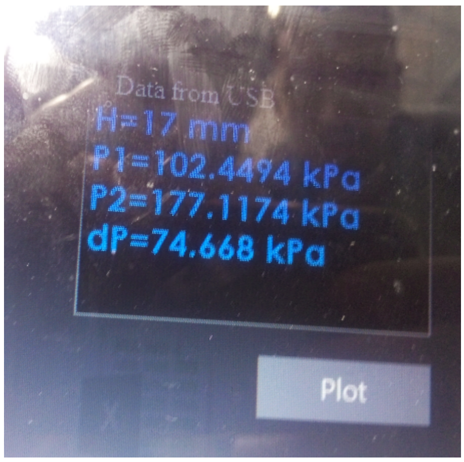
Now we will test our measuring system's response to more changing values.

B Test Two

During this test we have pushed the pressure sensor to it's limit and we've tested it with a pressure of 218 kPa. As expected the sensor fellow perfectly the variation of pressure indicated on the compressor's barometer.



(a) pressure on the compressor barometer



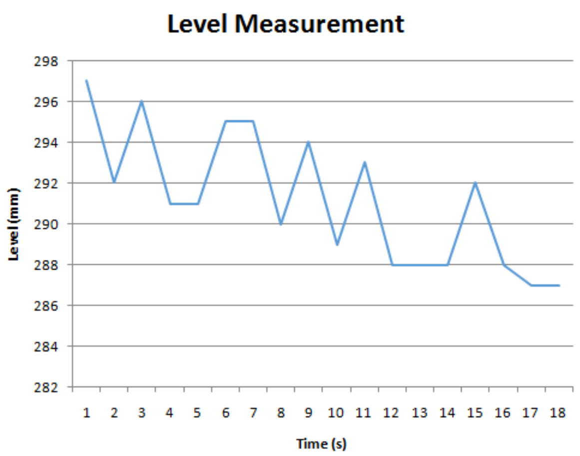
(b) pressure value coming from the sensor

Figure 3.12: pressure values

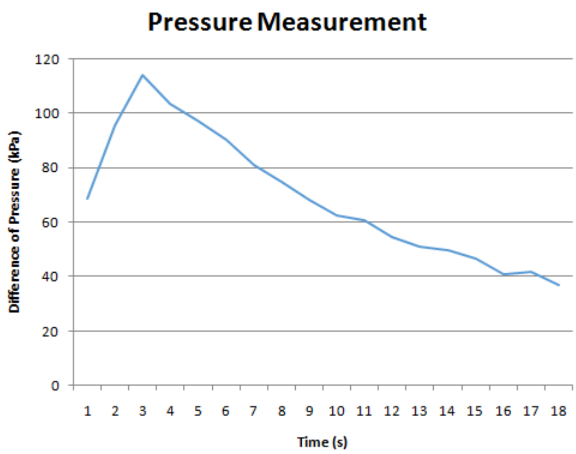
The values are registered in the table 3.2 and the graphics in figure 3.13.

Time (s)	Level (mm)	P1 (kPa)	P2 (kPa)	P2-P1 (kPa)
1	297	101.491	169.9297	68.4387
2	292	101.9702	197.2427	95.2725
3	296	104.8453	218.8056	113.9603
4	291	104.8453	208.2637	103.4184
5	291	103.6473	200.8365	97.1892
6	295	103.8869	194.1281	90.2412
7	295	102.2098	183.107	80.8972
8	290	102.4494	177.1174	74.668
9	294	103.8869	171.8464	67.9595
10	289	104.6057	166.8151	62.2094
11	293	103.1681	163.7005	60.5324
12	288	103.8869	158.4295	54.5426
13	288	104.3661	155.3149	50.9488
14	288	102.689	152.2003	49.5113
15	292	102.2098	148.6065	46.3967
16	288	104.6057	145.4918	40.8861
17	287	101.7306	143.5751	41.8445
18	287	103.8869	140.7001	36.8132
19	291	102.689	136.6271	33.9381
20	287	103.1681	111.71	8.5419

Table 3.2: Test Two : table of values



(a) Level



(b) Differential pressure

Figure 3.13: Test Two : graphics

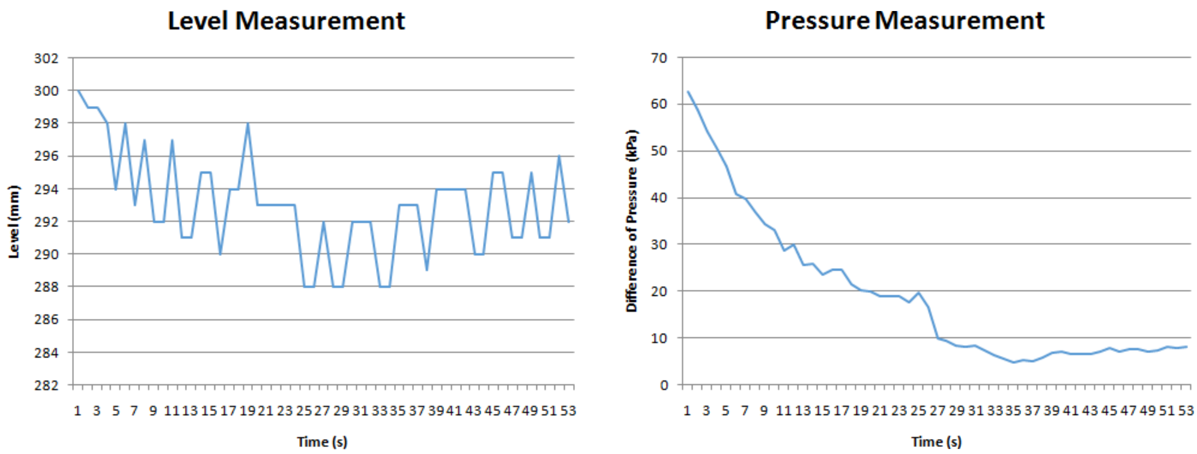
As seen in table and graphs, the pressure sensor fellow the variations of pressure until high values (218 kPa), the differential pressure reached 113 kPa and the level varied more significantly between 287 and 297 mm.

C Test Three

During this test, we scanned a large range of values in order to evaluate the sensors response to the changes in all the range of measurement. All the values are shown in table 3.3.

Time (s)	Level (mm)	P1 (kPa)	P2 (kPa)	P2-P1 (kPa)
1	300	103.4077	166.0963	62.6886
2	299	102.9286	161.7838	58.8552
3	299	103.6473	157.9504	54.3031
4	298	103.4077	153.8774	50.4697
5	294	102.689	149.3252	46.6362
6	298	104.3661	145.2522	40.8861
7	293	102.689	142.3772	39.6882
8	297	103.4077	140.2209	36.8132
9	292	102.2098	136.6271	34.4173
10	292	102.689	135.6687	32.9797
11	297	104.8453	133.5124	28.6671
12	291	102.689	132.5541	29.8651
13	291	104.3661	129.9186	25.5525
14	295	102.689	128.4811	25.7921
15	295	104.8453	128.2415	23.3962
16	290	101.9702	126.5644	24.5942
17	294	102.4494	127.0436	24.5942
18	294	103.1681	124.6477	21.4796
19	298	105.3244	125.3665	20.0421
20	293	103.1681	122.9706	19.8025
21	293	104.3661	123.2102	18.8441
22	293	102.689	121.5331	18.8441
23	293	104.6057	123.4498	18.8441
24	293	103.1681	120.8143	17.6462
25	288	102.9286	122.4914	19.5628
26	288	104.8453	121.5331	16.6878
27	292	103.6473	113.3871	9.7398
28	288	103.8869	113.1475	9.2606
29	288	103.6473	111.9496	8.3023
30	292	103.1681	111.2308	8.0627
31	292	102.4494	110.7516	8.3022
32	292	103.4077	110.7516	7.3439
33	288	103.8869	110.0329	6.146
34	288	104.6057	110.0329	5.4272
35	293	105.3244	110.0329	4.7085
36	293	105.0848	110.2725	5.1877
37	293	105.0848	110.0329	4.9481
38	289	104.8453	110.512	5.6667
39	294	104.3661	111.2308	6.8647
40	294	104.1265	111.2308	7.1043

Table 3.3: Test Three : table of values



(a) Level (b) Differential pressure

Figure 3.14: Test Three : graphics

We notice that the sensors have been able to follow the variations all over the range.

3.2.7 Error calculation

A Pressure sensor

Resolution the resolution of this sensor is given by 4 digits after the point, that means 0.1 Pa which is 1000 times better than the U tube manometer. The only problem is the precision that relies on the digits number of the microcontroller.

Precision The precision is generally limited by the number of digits available in the Analog/Digital converter at the microcontroller level. Hence, the precision can be calculated by dividing the quantum value on 2. In our case the precision is $\Delta P = \frac{1}{2}\frac{250}{2^{10}} = \pm 0.122kPa$.

Errors The maximum error is specified by the datasheet as the global maximization of all errors. It is equal to 3.45 kPa which is 1.5 % of the maximum pressure range. Rather than that, human errors are avoided as long as the values are read from a digital display and the sensors are not touched after being fixed.

B Ultrasonic transceiver

Resolution The resolution of the ultrasonic transceiver HC-SR04 can reach the 1mm perfectly.

Precision The precision of the ultrasonic transceiver HC-SR04 is given by the constructor and reaches 3 mm.

3.3 Conclusion

The experimental part is the real practical test of the system. We have tested the different sensors and devices in different conditions in order to examine the different properties of sensors such as reliability, precision and absolute error. We have analyzed the results in order to compare them with the theoretical notions. The system has improved its reliability and suitability for the conditions of the experiment.

Chapter 4

Future Outlook

4.1 Perspectives and Future Development

Level and Pressure sensor using HC-SR04 ultrasonic module and MPX4250AP transducer helped us achieving a good and accurate values for both level and pressure measurement, thanks to these sensors accuracy, simple installation and compatibility to our application, though we can always go far by including other technologies and measurement techniques in line with the applications requirements and industrial needs. Speed, costs reductions and more improvement in accuracy will be achieved in the future using measurement methods and sensors with higher performance, new manufacturing technologies, and sophisticated signal processing methods. The greater demand for environmental protection demands the development of highly reliable sensors. Maintenance-free sensors with long life expectancy and low electric power consumption will, thereby, be the focus of interests. The main development trends in sensor technology are, in general, toward miniaturization and an increasing use of multisensor and wireless systems, see fig 4.1. Moreover, further development and improvement of this project in the near future should be highly considered:

4.1.1 Microcontroller Alternatives

The PIC microcontroller was chosen because of its cheapest price and ease to program it (C programming language). However, other alternatives are available with higher performance, efficiency and multiple options, such as microprocessor, Application-specific integrated circuit (IC), Digital signal processors (DSP), Field Programmable Gate Array FPGA (fig 4.2b), Raspberry Pi (fig 4.2c), etc. Microcontrollers are the most suitable choice for sensor controlling due to their flexibility in connecting to other devices, programmability and low power consumption as parts of the controller are active other parts can hibernate. Microprocessor on the other hand, consumes more power, therefore it is not the most suitable choice for our measurement.

4.1.2 Multiple sensors and hardware duplication ability

Microcontrollers generally (PIC18F2550 in our case) have considerably a big number of pins (28 pins in our case, 13 of them include ADC), which give them the ability to assemble many sensors integration and acquisition in the same time using multiplexing or

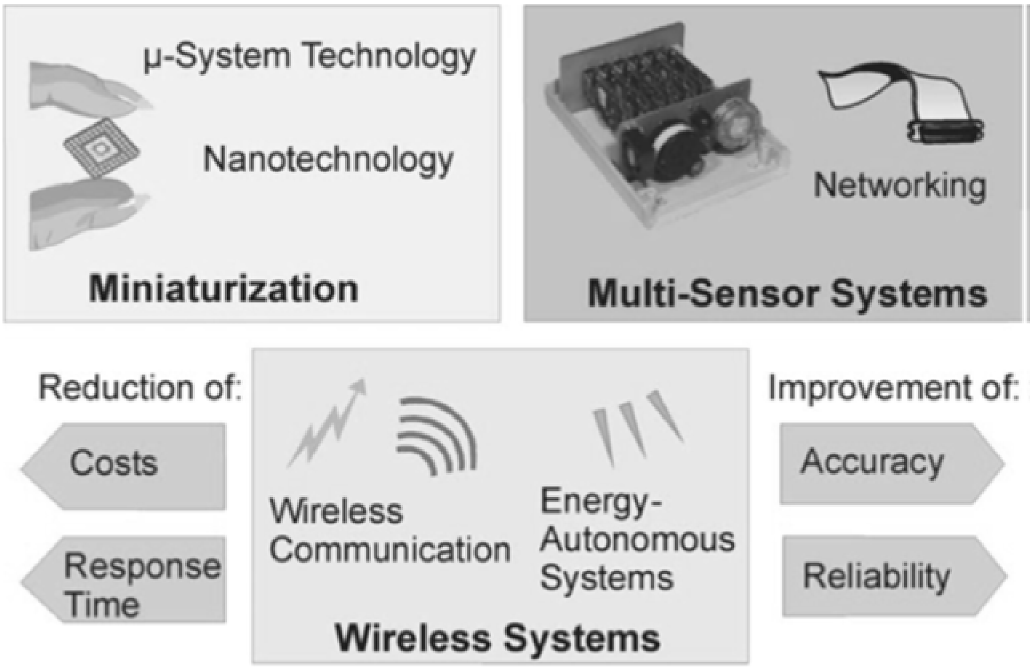
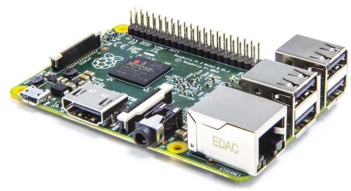


Figure 4.1: Future trends in sensor technology [35].

(a) µC PIC18F2550

(b) FPGA Xilinx spartan



(c) Raspberry Pi 2

Figure 4.2: Alternatives cards to microcontrollers.

parallel reading. In our project we have used two pressure transducers (MPX4250AP), so that we can determine the pressure difference between two points, and we have integrated them in the same circuit using the same microcontroller. Using the same principle, we can integrate multiple sensors for specific applications or needs.

4.1.3 Sensor combination

In our project, we have combined the level and pressure measurement in the same circuit using only one microcontroller and communication support (USB cable) to a general graphic user interface in order to be able to treat the different output data, and make a relative analysis and study. In the same way we can look forward next occasions for integrate more fluid parameters measurement using different sensors and technologies, in order to make this project more global for the different measurements in hydraulic field, and more suitable for measuring more complex parameters that need these basic measurements. This combination of different physical parameters will certainly make these measurement circuits more compatible and easy to access.
Multi-sensor systems can be divided into two types: centralized and distributed

A Centralized systems

In this kind of systems the data processing of all sensors is included in the central precessing unit (Microcontroller), which receives all sensors data in parallel, and correlate the absolute time correspondence of it, and the processing unit can control each sensor separately, and makes a quick response to any reaction for a specific sensor, figure 4.3 shows the centralized systems principle.

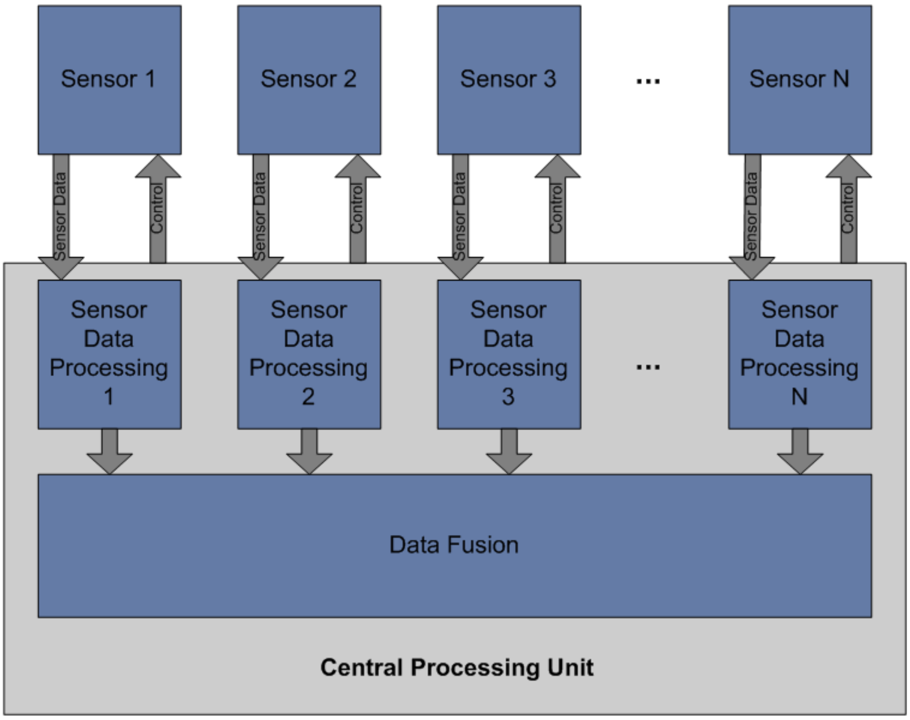


Figure 4.3: Centralized systems principle [36].

B Distributed systems

In distributed systems the data processing of each sensor is included with the sensor outside the central processing unit, this type is more complex and covers large area compared to the first type, and it sometimes suffers from several data loss and synchronisation, figure 4.4 shows the distributed systems principle.

4.1.4 Miniaturization

Miniaturization is an outstanding strategy of success in modern technologies. A reduction of characteristic dimensions usually results in shorter response times so that a correspondingly higher speed is achievable in signal generation and processing. In many cases, it reduces costs because of the higher integration rate, lower power consumption, and higher reliability. Miniaturization is generally gaining importance in all fields of applications, where smaller structures and greater precision are becoming decisive to the market acceptance of individual products. The development trend to miniaturization goes on within nanotechnologies, which will open up access to still smaller dimensions.

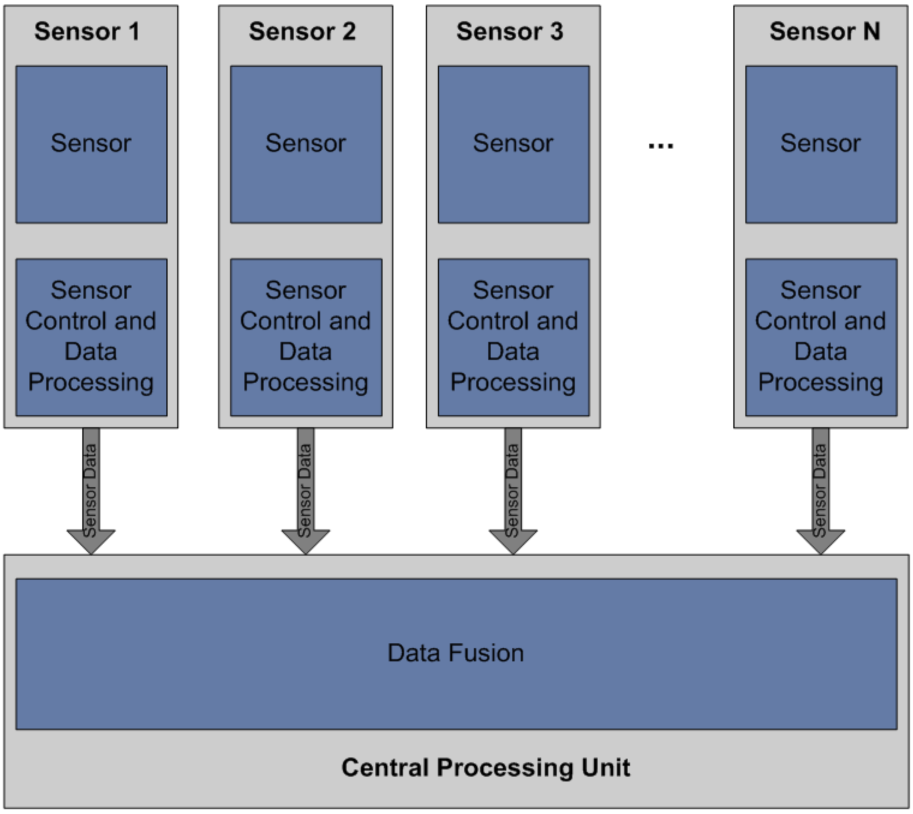


Figure 4.4: Centralized systems principle [36].

4.1.5 Wireless Connection

With the large amount of components, which are indispensable for the achievement of the required functionality, the electric wiring of spatially distributed systems becomes complex and causes difficulties in the system's handling. The use of wireless systems implies a better convenience and leads to a considerable cost reduction. Wireless sensor systems have the advantage that they can be placed anywhere, and can, therefore, record the measured quantity closely to its occurrence, independent of potential harsh circumstances. Wireless sensors can communicate over ultrasonic or infrared signals. For instance, surface acoustic wave devices (SAW transponders) can be used for object identification and for the measurement of physical, chemical, and biological quantities such as temperature, pressure, torque, acceleration, or humidity. Energy-autonomous sensors will gain a particular importance among wireless sensors because, in this case, wires are no longer necessary, even for electricity supply. This kind of sensor is necessary for many applications in which long distances are to be bridged, or a large number of distributed components are necessary [35].

4.1.6 The need of automation

The world indeed is moving towards new methodologies and technologies, and systems are growing exponentially and being too complex and exhaustive to run completely manually, so the need of automation is being critical in nowadays systems.

Automatic control is the use of various tools to operate and control different processes and systems and allows them to self-modify and adjust. Moreover, automation makes systems able to adapt and improve their operation control and service without human intervention with each reaction. Automation has also a considerable effect on increasing predictability and accuracy of our system, reducing human labor costs and can replace human intervention in hazardous conditions.

In our hydraulic system, the necessity of automation with the increase of measurement sensors and various systems can be in near future a critical choice, in order to improve the system accuracy and quality, and that will certainly need more cooperation between different departments, such as Automatics and Mechanics in addition to Electronics and Hydraulics.

4.1.7 Mobile application

Smartphones and tablets nowadays are equipped with different sensors and applications (Accelerometers, thermometers, Camera for taking pictures and videos, rotation of the screen, etc) that may help the user in measurement and control. Phone applications have the ability to make the circuit control more easy and wireless for better use, remote access and interactivity. Make for the project its own application will certainly take to another level considering the huge step that the world of smartphones has made in our daily life.

4.2 Problems encountered and proposed solutions

During the whole project, and passing its different parts, we have encountered some problems whose we have proposed many solutions that help us continue smoothly our progress to the final solution. From these problems we find:

4.2.1 Sensors adaptation

One of the major tasks of many sensory processing system is its adaptation to the system requirements, due to the sensor standardisation and generalisation. For this purpose, we need different approach to adapt the different sensors (Level and pressure sensors in our case) to our system limitations and constraints recommended by the hydraulic system we are measuring on. This development and adaptation is also dependent in part on the structure of the incoming sensory signals.

A Ultrasonic Level Sensor

For the level measurement, a specific sizing was needed to make the sensor suitable for water pipes and tanks size limitation, also wave guiding through pipes architecture was an inevitable task in order to limit ultrasound waves interferences due to beam width or the emitter directivity which can cause many problems of interference and false detection due to the wall reflections.

B Pressure Sensor

For the pressure measurement, we have also encountered some problems adjusting the pressure transducer input size to liquid pipes dimensions. Also, since the MPX4250AP pressure transducer is not a waterproof sensor, several cautions and adjustment was needed to make a non humid and clean environment measuring indirect liquid pressure from air pressure measurement instead of direct liquid pressure measurement.

4.2.2 Sensors calibration

Nowadays, Sensors are being more sophisticated and have a sufficient accuracy, at least, for specific applications. However, if we want to achieve the best possible accuracy and resolution we need certainly to calibrate the sensor according to the system where it will be used (see figure 4.5). Nevertheless, the sensor is not the only component in the operation system, other system components may most likely affect the output accuracy.

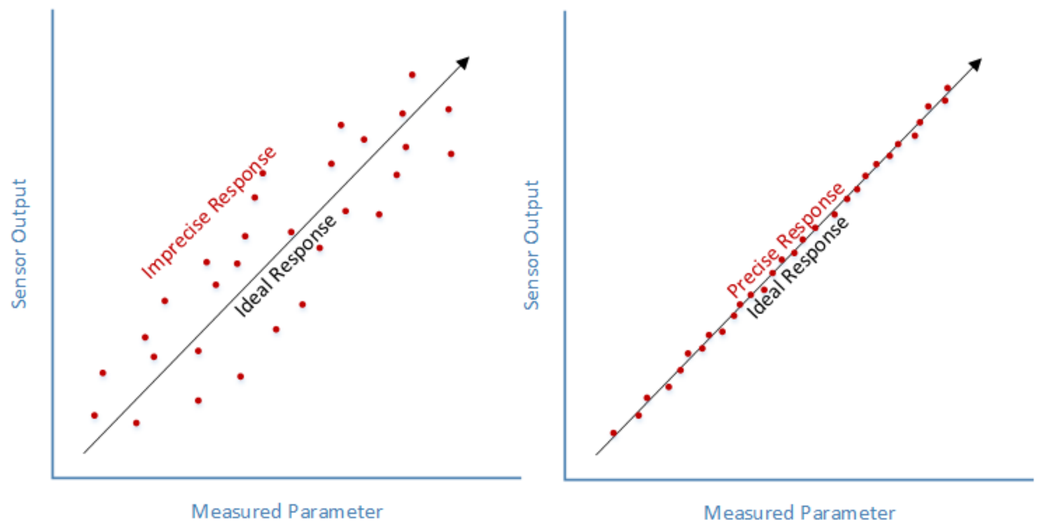


Figure 4.5: the effect of the calibration on the response precision.

In order to check the pressure values measured by our pressure sensor, we need to calibrate the sensor comparing its output to another pressure measurement method. Exploiting the practical materials available in hydraulic laboratory, we were limited by using the U-tube manometer as a calibrating tool in order to increase the sensor accuracy and make it more reliable.
Using several references values we have got good results with high precision and reliability, and we were able to get a reasonable difference of pressure, even under certain conditions.

4.2.3 Flow measurement problem

Until now, we have succeed to make a reliable system that can measure with a good accuracy liquid level using ultrasonic and infrared sensors, as well as the difference of pressure between two different points in the hydraulic system. Furthermore, the ability of our circuit to be more developed and support more sensors and measurement led us to think of measuring the fluid flow through the system pipes.
Fluid flow measurement generally needs a high accuracy and resolution, and flowmeters should be unaffected by its environment. In addition, the nature of liquid systems often oblige us to use extrinsic sensors in order to isolate the liquid from environmental factors which can occasionally falsify the sensor measurements.

For this purpose, we have developed a flowmeter which can measure liquid flow from the difference of pressure created introducing a constriction in the liquid pipe. The flow

measurement from the difference of pressure uses Bernouli's equation to deduce the liquid flow.
This approach uses different techniques to measure pressure, so we can deduce the liquid flow from it. In our Master project, we will use liquid manometer thanks to its ease to operate, low cost and acceptable accuracy and sensitivity. This technique will be detailed in the Master thesis explaining all the results we obtained.

4.3 Conclusion

The electronic part of the system should progress step by step in parallel with the hydraulic part. Hence, the electronic system needs continuous development and modifications in order to fit the changing conditions of the hydraulic system.

Conclusion

Electronic measurement methods offer many advantages and dominate in quality, precision and performance over all other measuring methods. It also offers processing and storage possibility with real-time display. Furthermore, the electronic sensors can be calibrated to give the desired results under all experimental conditions. As technology is developed, sensors and electronic devices are becoming smaller and easier to integrate in all systems, this makes their implementation possible in all sorts of systems.

We have done our studies in order to understand all the physical phenomena interfering in the system and to choose the most suitable electronic devices that replace the previous measuring methods. We have chosen the sensors having in evidence the technical performance toe to toe with seeking for the most rational quality-price ratio.

As seen in our project, we took advantage of all the characteristics mentioned above to replace the old traditional measurement methods with the new electronic ones. We have been able to test their reliability and suitability to the system in focus under different conditions and our measuring system has shown a spotless performance regardless of the different circumstances that it has been put through. We also used the electronic processing to visualize, in real-time, the data coming from the sensors, plot it and store it in computer.

Finally we have calculated the system's errors in order to evaluate its performance and efficiency.

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Appendix A

Technical support

1.1 Properties of the ultrasonic module HC-SR04

1.1.1 Product features

Ultrasonic ranging module HC-SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitter, receiver and control circuit. The basic principle of work [26]:

- Using trigger input for at least 10us high level signal.
- The Module automatically sends eight 40 kHz pulses and detect whether there is a pulse signal back.
- If the signal back, through high level , time of high echo output duration is the time from sending ultrasonic to returning.

1.1.2 Wire connecting direct as following:

- 5V Supply.
- Trigger Pulse Output.
- Echo Pulse Input.
- 0V Ground.

1.1.3 Electrical Parameters:

Working Voltage	DC 5 V
Working Current	15mA
Working Frequency	40kHz
Max Range	4m
Min Range	2cm
Measuring Angle	15 degree
Trigger Input Signal	10uS TTL pulse
Echo Output Signal	Input TTL lever signal and the range in proportion
Dimension	45*20*15mm

Table 1.1: Electrical Parameters [26].

1.2 Operating characteristics of MPX4250AP sensor

The different operating characteristics of the MPX4250AP pressure sensor are shown in the table 1.2 below:

Characteristic	Min	Typ	Max	Unit
Pressure Range	20	—	250	kPa
Supply Voltage	4.85	5.1	5.35	V
Supply Current	—	7.0	10	mAdc
Minimum Pressure Offset	4.622	4.692	4.762	V
Full Scale Output	4.622	4.692	4.762	V
Full Scale Span	4.622	4.692	4.762	V
Accuracy	—	—	± 1.5	%
Sensitivity	—	20	—	mV/kPa
Response Time	—	1.0	—	ms
Output Source Current at Full Scale Output	—	0.1	—	mA
Warm–Up Time	—	20	—	ms
Offset Stability	—	± 0.5	—	%

Table 1.2: Operating characteristics of MPX4250AP sensor [27].

A Features

- 1.5% Maximum Relative Error Over 0° to 85°C.
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems.
- Ideally Suited for Direct Microprocessor Interfacing.
- Patented Silicon Shear Stress Strain Gauge.
- Temperature Compensated Over –40° to +125°C.
- Offers Reduction in Weight and Volume Compared to Existing Hybrid Modules.

- Ideal for Non–Automotive Applications.

1.3 Properties of the Microcontroller PIC18F2550

1.3.1 Universal Serial Bus Features

- USB V2.0 Compliant
- Low Speed (1.5 Mb/s) and Full Speed (12 Mb/s)
- Supports Control, Interrupt, Isochronous and Bulk Transfers
- Supports up to 32 Endpoints (16 bidirectional)
- 1-Kbyte Dual Access RAM for USB
- On-Chip USB Transceiver with On-Chip Voltage Regulator
- Interface for Off-Chip USB Transceiver
- Streaming Parallel Port (SPP) for USB streaming transfers (40/44-pin devices only)

1.3.2 Power-Managed Modes

- Run: CPU on, peripherals on
- Idle: CPU off, peripherals on
- Sleep: CPU off, peripherals off
- Idle mode currents down to 5.8 μA typical
- Sleep mode currents down to 0.1 μA typical
- Timer1 Oscillator: 1.1 μA typical, 32 kHz, 2V
- Watchdog Timer: 2.1 μA typical
- Two-Speed Oscillator Start-up

1.3.3 Flexible Oscillator Structure

- Four Crystal modes, including High Precision PLL for USB.
- Two External Clock modes, up to 48 MHz.
- Internal Oscillator Block: 8 user-selectable frequencies, from 31 kHz to 8 MHz. User-tunable to compensate for frequency drift.
- Secondary Oscillator using Timer1 @ 32 kHz
- Dual Oscillator options allow microcontroller and USB module to run at different clock speeds
- Fail-Safe Clock Monitor: Allows for safe shutdown if any clock stops

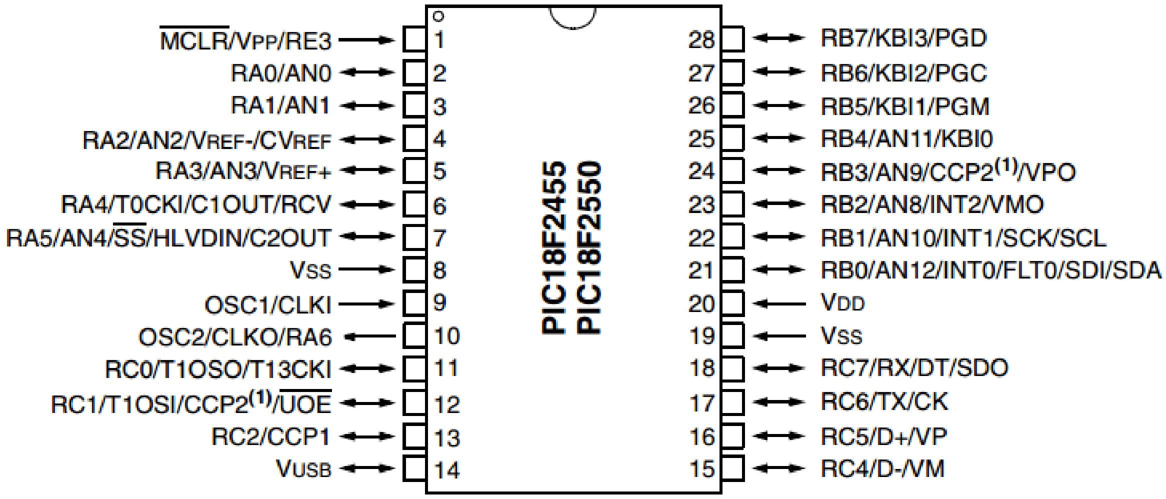

Figure 1.1: PIN definition of PIC18f2550 [31].

1.3.4 Peripheral Highlights

- High-Current Sink/Source: 25 mA/25 mA
- Three External Interrupts
- Four Timer modules (Timer0 to Timer3)
- Up to 2 Capture/Compare/PWM (CCP) modules:
  - Capture is 16-bit, max. resolution 5.2 ns (TCY/16)
  - Compare is 16-bit, max. resolution 83.3 ns (TCY)
  - PWM output: PWM resolution is 1 to 10-bit
- Enhanced Capture/Compare/PWM (ECCP) module:
  - Multiple output modes
  - Selectable polarity
  - Programmable dead time
  - Auto-shutdown and auto-restart
- Enhanced USART module: LIN bus support
- Master Synchronous Serial Port (MSSP) module supporting 3-wire SPI (all 4 modes) and I2C™ Master and Slave modes
- 10-bit up to 13-channel Analog-to-Digital Converter module (A/D) with Programmable Acquisition Time
- Dual Analog Comparators with Input Multiplexing

1.3.5 Special Microcontroller Features

- C Compiler Optimized Architecture with optional Extended Instruction Set
- 100,000 Erase/Write Cycle Enhanced Flash Program Memory typical
- 1,000,000 Erase/Write Cycle Data EEPROM Memory typical
- Flash/Data EEPROM Retention: $>$ 40 years
- Self-Programmable under Software Control
- Priority Levels for Interrupts
- 8 x 8 Single-Cycle Hardware Multiplier
- Extended Watchdog Timer (WDT):Programmable period from 41 ms to 131s
- Programmable Code Protection
- Single-Supply 5V In-Circuit Serial Programming™ (ICSP™) via two pins
- In-Circuit Debug (ICD) via two pins
- Optional dedicated ICD/ICSP port (44-pin devices only)
- Wide Operating Voltage Range (2.0V to 5.5V)

1.4 The pin description of RS232 connector

The pin description given below is in the order of the priorities in which they are used in DB9 connector:

- Pin 3: TXD- This pin is used to serially transmit the bits to the device connected to it. They are permanently set by the hardware
- Pin 2: RXD- The data is received by the computer in serial order by the receive pin. It is also permanently set by the hardware.
- Pin 7/Pin 8: RTS/CTS- The ready to send and clear to send pins are for hardware control flow. Hardware flow control is very useful when there is mismatching between the transmitter and receiver in terms of rate of speed.
- Pin 6: DSR: Data Set Ready pin is generally utilized in devices like modem to tell computer that it is ready to take data.
- Pin 4: DTR: The DTR is a control signal set to high-low. It tells the device to disconnect from computer.
- Pin 1: DCD: This Data Carrier Detect is another type of pin configured by software for control signaling purpose. It is used to by computer to detect whether the device has been disconnected from it. Apart from the disconnection between computer and the device, it also detects whether the connected device has lost its other connections. For example, in a modem, computer can detect whether it has lost its connection from the phone line.

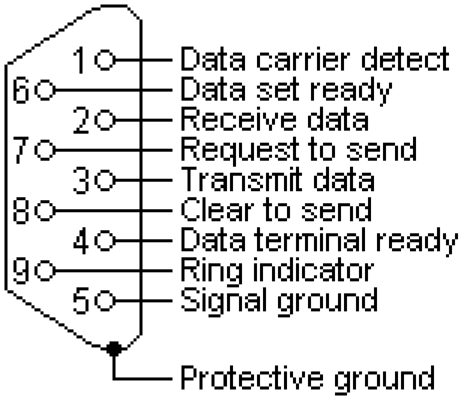

Figure 1.2: Pin description in RS-232 [29].

- Pin 9: RI- As its name suggests, ring indicator indicates the computer that modem is ringing. It is a one way type of communication taking place from modem to computer.
- Pin 5: SG- The signal ground provides ground to the overall connections. It also acts as reference point from where signals can be measured.

Appendix B

Programs

2.1 PIC18F2550 program

```
// LCD module connections
sbit LCD_RS at RB4_bit;
sbit LCD_EN at RB5_bit;
sbit LCD_D4 at RB0_bit;
sbit LCD_D5 at RB1_bit;
sbit LCD_D6 at RB2_bit;
sbit LCD_D7 at RB3_bit;
sbit LCD_RS_Direction at TRISB4_bit;
sbit LCD_EN_Direction at TRISB5_bit;
sbit LCD_D4_Direction at TRISB0_bit;
sbit LCD_D5_Direction at TRISB1_bit;
sbit LCD_D6_Direction at TRISB2_bit;
sbit LCD_D7_Direction at TRISB3_bit;
// End LCD module connections

//----------------------------------------------------------------
unsigned char readbuff[64] absolute 0x500;
unsigned char writebuff[64] absolute 0x540;
// We create two buffers: one for sending data to USB
// and one for receiving data from USB.
//----------------------------------------------------------------

void interrupt()
{
  USB_Interrupt_Proc();      // Activating USB servicing inside the interrupt
}

int cnt=0;                            //global variable declaration

void main()
{
  //Variable declaration

  unsigned long d1;
    unsigned long d2;
  float d,da,db;
```

```
int a,m,n,l;
char txt[3];
char txt1[8];
char txt2[10];

ADC_Init();                     // Initialize Analog Digital Converters
ADCON1=0x0E;          // Analog PINs specification

Lcd_Init();        /initialization of LCD
Lcd_Cmd(_LCD_CLEAR);       // Clear display
Lcd_Cmd(_LCD_CURSOR_OFF);  // Cursor off

TRISB = 0b10000000;        //RB7 as Input PIN (ECHO for ultrasonic)

HID_Enable(&readbuff,&writebuff);  // Enable HID communication
Lcd_Out(1,1,"Developed By");   //writing on LCD
Lcd_Out(2,1,"PolyTech");

Delay_ms(3000);
Lcd_Cmd(_LCD_CLEAR);

T1CON = 0x10;              //Initialize Timer Module
while(1)
  {
  TMR1H = 0;                //Sets the Initial Value of Timer
    TMR1L = 0;                //Sets the Initial Value of Timer

  //Pulse generating
    PORTB.F6 = 1;           //TRIGGER HIGH (RB6 as an output for ultrasonic
       trigger)
    Delay_us(10);             //10uS Delay
    PORTB.F6 = 0;             //TRIGGER LOW

    while(!PORTB.F7);         //Waiting for Echo
    T1CON.F0 = 1;             //Timer Starts
    while(PORTB.F7);          //Waiting for Echo goes LOW
    T1CON.F0 = 0;             //Timer Stops

    a = (TMR1L | (TMR1H<<8)); //Reads Timer Value
    a = a/5.882;              //Converts Time to Distance

  if(a>=20 && a<=24000)       //Check whether the result is valid or not
      { a=a/5.7;    //distance calibration
          a = a + 1;
        IntToStr(a,txt); //Conversion of the value to character
        Ltrim(txt);   // cutting the character string

    //display the character on the LCD
    Lcd_Cmd(_LCD_CLEAR);
        Lcd_Out(1,1,"Distance = ");
        Lcd_Out(1,12,txt);
        Lcd_Out(1,15,"mm");
```

```
   //Copying data to the USB writing buffer
         if(a<100) l=2;
         else l=3;
         for(cnt=0;cnt<l;cnt++)
         writebuff[cnt]=txt[cnt];
         writebuff[l]=';';
         }
else
      {
       Lcd_Cmd(_LCD_CLEAR);
       Lcd_Out(1,1,"Out of Range");
      }

Delay_ms(1000);       //waiting

   //First pressure sensor

      d1=ADC_Read(1); //Reading the index from the analog digital converter
      da=d1;
      da=da*5/1023; //Calculating the voltage equivalent to the index

   //Sensor calibration
      da=((da/5.1)+0.04)/0.004;
      da=da+5;

         FloatToStr(da, txt1);         // Convert voltage to string
         Ltrim(txt1);
         Lcd_Out(1,1,"Pres1 = ");
         Lcd_Out(1,9,txt1);
         Lcd_Out(1,15,"cm");

   //Copying data to USB write buffer
   if(da<100) m=7;
      else m=8;
         for(cnt=l+1;cnt<l+m+1;cnt++)
         writebuff[cnt]=txt1[cnt-l-1];
         writebuff[l+m+1]=';';

   //Second pressure sensor

   d2= ADC_Get_Sample(0);
      d2=ADC_Read(0);
      db=d2;
      db=db*5/1023;
      db=((db/5.1)+0.04)/0.004;
      db=db+3;

      FloatToStr(db, txt2);
         Ltrim(txt2);
         Lcd_Out(2,1,"Pres2 = ");
         Lcd_Out(2,9,txt2);
         for(cnt=l+m+2;cnt<l+m+12;cnt++)
         writebuff[cnt]=txt2[cnt-l-m-2];
```

```
            hid_write(&writebuff,64); //sending the USB write buffer to USB data
                PINs

            Delay_ms(1000);
         }
}
```

2.2 GUI Program

2.2.1 The start form program

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;
using easyUSBHidNetClass;
using Excel = Microsoft.Office.Interop.Excel;
using System.Reflection;

namespace USB_HID
{
    public partial class Form2 : Form
    {
        public Form2()
        {
            InitializeComponent();
        }
        private void Form2_Load(object sender, EventArgs e)
        {
        }
            private void Form2_FormClosed(object sender, FormClosedEventArgs e)
        {
            var EXCELProcesses =
                System.Diagnostics.Process.GetProcesses().Where(pr =>
                pr.ProcessName == "EXCEL");

            foreach (var process in EXCELProcesses)
            {
                process.Kill();
            }
        }

        private void button2_Click(object sender, EventArgs e)
        {
            this.Hide();
            Form3 f3 = new Form3();
```

```
            f3.ShowDialog();
            this.Close();
        }
    }
}
```

2.2.2 The main form program

```
using System;
using System.Drawing;
using System.Windows.Forms;
using easyUSBHidNetClass;
using Excel = Microsoft.Office.Interop.Excel;
using System.Reflection;

namespace USB_HID
{
    public partial class Form3 : Form
    {
        byte[] DataWrite = new byte[64];  //Buffer USB write
        byte[] DataRead = new byte[64];   //Buffer USB Read

        int i = 3;

        static Excel.Application xlApp = new Excel.Application(); //creating
            Excel file
        static Excel.Workbook xlWorkBook;
        static Excel.Worksheet xlWorkSheet;
        static object misValue = System.Reflection.Missing.Value;

        public Form3()
        {
            InitializeComponent();
            easyUSBHidNetClass1.SerialNumber =
                "{6FE5DD5B-5777-4709-A45C-BC018E478FD1}"; //USB HID serial number
        }
        protected override void OnHandleCreated(EventArgs e)
        {
            base.OnHandleCreated(e);
            easyUSBHidNetClass1.RegisterHandle(Handle);
        }

        protected override void WndProc(ref Message m)
        {
            easyUSBHidNetClass1.USBHidMensagens(ref m);
            base.WndProc(ref m);
        }

        private void easyUSBHidNetClass1_anyDeviceUSB_found(object sender,
            EventArgs e) //test USB
        {

            label_status.Text = "USB Device Detected";
```

```
    label_status.ForeColor = System.Drawing.Color.LawnGreen;

}

private void easyUSBHidNetClass1_anyDeviceUSB_removed(object sender,
    EventArgs e)
{
    label_status.Text = "USB Device Removed";
    label_status.ForeColor = Color.FromArgb(251, 9, 33);

}


// Reading data from USB
private void easyUSBHidNetClass1_DeviceUSB_dataReceived(object sender,
    easyUSBHidNetClass.DataRecievedEventArgs args)// data received here
{
    if (InvokeRequired)
    {
        Invoke(new
            DataRecievedEventHandler(easyUSBHidNetClass1_DeviceUSB_dataReceived),
            new object[] { sender, args });
    }
    else
    {
        try
        {
            if (button1.Enabled == false)
            {
                System.Text.Encoding enc = System.Text.Encoding.ASCII;
                string[] Result =
                    enc.GetString((byte[])args.data).Split('\0');
                string[] tab = Result[0].Split(';');
                xlWorkSheet.Cells[i, 1] = (i - 2);
                //Write received data on the excel file
                xlWorkSheet.Cells[i, 2] = tab[0];
                xlWorkSheet.Cells[i, 4] = tab[1];
                xlWorkSheet.Cells[i, 5] = tab[2];
                xlWorkSheet.Cells[i, 6] = tab[3];
                xlWorkSheet.Cells[i, 3] = tab[4];

                textBox.Multiline = true;
                textBox.Clear();
                //Write on received data on the interface display
                textBox.Text += "H1=" + tab[0] + " mm" +
                    Environment.NewLine;
                textBox.Text += "H2=" + tab[4] + " mm" +
                    Environment.NewLine;
                textBox.Text += "P1=" + tab[1] + " kPa" +
                    Environment.NewLine;
                textBox.Text += "P2=" + tab[2] + " kPa" +
                    Environment.NewLine;
                textBox.Text += "dP=" + tab[3] + " kPa" +
```

```
                    Environment.NewLine;
                i++;
            }
        }
        catch { }
    }
}

//Writing data on the USB
private void easyUSBHidNetClass1_DeviceUSB_dataSent(object sender,
    EventArgs e)
{
}

// Detection of our HID USB device
private void easyUSBHidNetClass1_DeviceUSB_found(object sender,
    EventArgs e)// event when your device found
{
    label_status.Text = "HID USB Device Detected";
}

private void easyUSBHidNetClass1_DeviceUSB_removed(object sender,
    EventArgs e)// event when your device removed
{
    label_status.Text = "USB Device Removed";

}


// Preparation of Excel file
private void Form3_Load(object sender, EventArgs e)
{

    if (xlApp == null)
    {
        MessageBox.Show("Excel is not properly installed!!");
        return;
    }

    xlWorkBook = xlApp.Workbooks.Add(misValue);
    xlWorkSheet = (Excel.Worksheet)xlWorkBook.Worksheets.get_Item(1);
    xlWorkSheet.Cells[2, 1] = "Time (s)";
    xlWorkSheet.Cells[2, 2] = "Level US(mm)";
    xlWorkSheet.Cells[2, 3] = "Level IR(mm)";
    xlWorkSheet.Cells[2, 4] = "P1 (kPa)";
    xlWorkSheet.Cells[2, 5] = "P2 (kPa)";
    xlWorkSheet.Cells[2, 6] = "P2-P1 (kPa)";
}

// USB identification
private void Form3_Activated(object sender, EventArgs e)
{
    easyUSBHidNetClass1.DeviceUSB_Config_VID_PID(0x1234, 0x0001);
```

```
}

private void button1_Click(object sender, EventArgs e) //Read button
    click event
{
    button1.Enabled = false;
    button2.Enabled = true;
    button3.Enabled = true;

    System.IO.Directory.CreateDirectory("D:\\Liquid Sensor");
}

// Save Excel file
private void button2_Click(object sender, EventArgs e) //save button
    click event
{
    button2.Enabled = false;
    Excel.Range Rng = xlWorkSheet.get_Range("A1", "Z1");
    xlWorkSheet.get_Range("A1", "Z1").Cells.Font.Size = 20;
    Rng.Value2 = textBox2.Text;
    Rng.Merge(Missing.Value);

    string path = "D:\\Liquid Sensor\\" + textBox1.Text + " " +
        DateTime.Now.ToString("dd-MM-yyyy HH;mm");

    xlWorkBook.SaveAs(path, Excel.XlFileFormat.xlOpenXMLWorkbook,
        misValue, misValue, misValue, misValue,
        Excel.XlSaveAsAccessMode.xlNoChange, misValue, misValue,
        misValue, misValue, misValue);
    xlWorkBook.Close(true, misValue, misValue);
    xlApp.Quit();

    releaseObject(xlWorkSheet);
    releaseObject(xlWorkBook);
    releaseObject(xlApp);

    MessageBox.Show("File saved Disk 'D:\\Liquid Sensor'");

    button1.Enabled = true;
    Application.Restart();
    Environment.Exit(0);
}

static private void releaseObject(object obj)
{
    try
    {
        System.Runtime.InteropServices.Marshal.ReleaseComObject(obj);
        obj = null;
    }
    catch (Exception ex)
    {
        obj = null;
```

```
            MessageBox.Show("Exception Occured while releasing object " +
                ex.ToString());
        }
        finally
        {
            GC.Collect();
        }
    }

    private void button3_Click(object sender, EventArgs e) // Plot button
        click event
    {
        button3.Enabled = false;
        xlWorkSheet.Columns.AutoFit();

        xlWorkSheet.Cells[2, 7] = "Average US";
        xlWorkSheet.Range["G3"].Formula = "=AVERAGE(B2: B" + (i -
            1).ToString() + ")";

        xlWorkSheet.Cells[5, 7] = "Ecart-type";
        xlWorkSheet.Range["G6"].Formula = "=STDEV(B2: B" + (i -
            1).ToString() + ")";

        xlWorkSheet.Cells[8, 7] = "Precision";
        xlWorkSheet.Range["G9"].Formula = "=STDEV(B2: B" + (i -
            1).ToString() + ")/ AVERAGE(B2: B" + (i - 1).ToString() + ")";


        xlWorkSheet.Cells[2, 8] = "Average IR";
        xlWorkSheet.Range["H3"].Formula = "=AVERAGE(C2: C" + (i -
            1).ToString() + ")";

        xlWorkSheet.Cells[5, 8] = "Ecart-type";
        xlWorkSheet.Range["H6"].Formula = "=STDEV(C2: C" + (i -
            1).ToString() + ")";

        xlWorkSheet.Cells[8, 8] = "Precision";
        xlWorkSheet.Range["H9"].Formula = "=STDEV(C2: C" + (i -
            1).ToString() + ")/ AVERAGE(C2: C" + (i - 1).ToString() + ")";


        xlWorkSheet.Cells[2, 9] = "Average P";
        xlWorkSheet.Range["I3"].Formula = "=AVERAGE(F2: F" + (i -
            1).ToString() + ")";

        xlWorkSheet.Cells[5, 9] = "Ecart-type";
        xlWorkSheet.Range["I6"].Formula = "=STDEV(F2: F" + (i -
            1).ToString() + ")";

        xlWorkSheet.Cells[8, 9] = "Precision";
        xlWorkSheet.Range["I9"].Formula = "=STDEV(F2: F" + (i -
            1).ToString() + ")/ AVERAGE(F2: F" + (i - 1).ToString() + ")";
```

```
xlWorkSheet.Cells[1, 1].Font.Bold = true;
xlWorkSheet.Cells[2, 1].Font.Bold = true;
xlWorkSheet.Cells[2, 2].Font.Bold = true;
xlWorkSheet.Cells[2, 3].Font.Bold = true;
xlWorkSheet.Cells[2, 4].Font.Bold = true;
xlWorkSheet.Cells[2, 5].Font.Bold = true;
xlWorkSheet.Cells[2, 6].Font.Bold = true;
xlWorkSheet.Cells[2, 7].Font.Bold = true;
xlWorkSheet.Cells[5, 7].Font.Bold = true;
xlWorkSheet.Cells[8, 7].Font.Bold = true;
xlWorkSheet.Cells[2, 8].Font.Bold = true;
xlWorkSheet.Cells[5, 8].Font.Bold = true;
xlWorkSheet.Cells[8, 8].Font.Bold = true;
xlWorkSheet.Cells[2, 9].Font.Bold = true;
xlWorkSheet.Cells[5, 9].Font.Bold = true;
xlWorkSheet.Cells[8, 9].Font.Bold = true;


// Plot the ultrasonic level graph
Excel.ChartObjects xlCharts2 =
    (Excel.ChartObjects)xlWorkSheet.ChartObjects(Type.Missing);
Excel.ChartObject myChart2 = (Excel.ChartObject)xlCharts2.Add(430,
    25, 380, 300);
Excel.Chart chartPage2 = myChart2.Chart;

var x2Range = xlWorkSheet.get_Range("A3", "A" + (i - 1).ToString());
var y2Range = xlWorkSheet.get_Range("B3", "B" + (i - 1).ToString());

Excel.SeriesCollection seriesCollection2 =
    chartPage2.SeriesCollection();

Excel.Series series2 = seriesCollection2.NewSeries();
series2.XValues = x2Range;
series2.Values = y2Range;
chartPage2.ChartType = Excel.XlChartType.xlLine;
chartPage2.HasTitle = true;
chartPage2.ChartTitle.Text = "Level Measurement";
chartPage2.Legend.LegendEntries(chartPage2.Legend.LegendEntries().Count).Delete();

Excel.Axis yAxis2 =
    (Excel.Axis)chartPage2.Axes(Excel.XlAxisType.xlValue,
    Excel.XlAxisGroup.xlPrimary);
yAxis2.HasTitle = true;
yAxis2.AxisTitle.Text = "Level (mm)";
yAxis2.AxisTitle.Orientation = Excel.XlOrientation.xlUpward;

Excel.Axis xAxis2 =
    (Excel.Axis)chartPage2.Axes(Excel.XlAxisType.xlCategory,
    Excel.XlAxisGroup.xlPrimary);
xAxis2.HasTitle = true;
xAxis2.AxisTitle.Text = "Time (s)";
xAxis2.AxisTitle.Orientation = Excel.XlOrientation.xlHorizontal;
```

```
// Plot the infrared level graph

var y3Range = xlWorkSheet.get_Range("C3", "C" + (i - 1).ToString());

Excel.SeriesCollection seriesCollection3 =
    chartPage2.SeriesCollection();
Excel.Series series3 = seriesCollection3.NewSeries();
series3.XValues = x2Range;
series3.Values = y3Range;

Excel.Axis yAxis3 =
    (Excel.Axis)chartPage2.Axes(Excel.XlAxisType.xlValue,
    Excel.XlAxisGroup.xlPrimary);
Excel.Axis xAxis3 =
    (Excel.Axis)chartPage2.Axes(Excel.XlAxisType.xlCategory,
    Excel.XlAxisGroup.xlPrimary);


// Plot the pressure graph
Excel.ChartObjects xlCharts =
    (Excel.ChartObjects)xlWorkSheet.ChartObjects(Type.Missing);
Excel.ChartObject myChart = (Excel.ChartObject)xlCharts.Add(600, 25,
    380, 300);
Excel.Chart chartPage = myChart.Chart;

var xRange = xlWorkSheet.get_Range("A3", "A" + (i - 1).ToString());
var yRange = xlWorkSheet.get_Range("F3", "F" + (i - 1).ToString());

Excel.SeriesCollection seriesCollection =
    chartPage.SeriesCollection();

Excel.Series series1 = seriesCollection.NewSeries();
series1.XValues = xRange;
series1.Values = yRange;
chartPage.ChartType = Excel.XlChartType.xlLine;
chartPage.HasTitle = true;
chartPage.ChartTitle.Text = "Pressure Measurement";
chartPage.Legend.LegendEntries(chartPage.Legend.LegendEntries().Count).Delete();

Excel.Axis yAxis =
    (Excel.Axis)chartPage.Axes(Excel.XlAxisType.xlValue,
    Excel.XlAxisGroup.xlPrimary);
yAxis.HasTitle = true;
yAxis.AxisTitle.Text = "Difference of Pressure (kPa)";
yAxis.AxisTitle.Orientation = Excel.XlOrientation.xlUpward;

Excel.Axis xAxis =
    (Excel.Axis)chartPage.Axes(Excel.XlAxisType.xlCategory,
    Excel.XlAxisGroup.xlPrimary);
xAxis.HasTitle = true;
xAxis.AxisTitle.Text = "Time (s)";
```

```
            xAxis.AxisTitle.Orientation = Excel.XlOrientation.xlHorizontal;

            //export level chart as picture file
            chartPage.Export(@"D:\\Liquid Sensor\\" + textBox1.Text + " " +
                DateTime.Now.ToString("dd-MM-yyyy HH;mm") + "-Level" + ".bmp",
                "BMP", misValue);

            //load picture to picturebox
            pictureBox1.Image = new Bitmap(@"D:\\Liquid Sensor\\" +
                textBox1.Text + " " + DateTime.Now.ToString("dd-MM-yyyy HH;mm") +
                "-Level" + ".bmp");

            chartPage2.Export(@"D:\\Liquid Sensor\\" + textBox1.Text + " " +
                DateTime.Now.ToString("dd-MM-yyyy HH;mm") + "-Pressure" + ".bmp",
                "BMP", misValue);
            pictureBox2.Image = new Bitmap(@"D:\\Liquid Sensor\\" +
                textBox1.Text + " " + DateTime.Now.ToString("dd-MM-yyyy HH;mm") +
                "-Pressure" + ".bmp");

        }
    }
}
```