Algerian Journal of Research and Technology
https://doi.org/10.58681/ajrt.22060103
A.J.R.T Volume 6 (N°1) (2022) 19 – 28
Selection and peer-review under responsibility of the scientific committee of The 1st International Symposium on INDUSTRIAL ENGINEERING, MAINTENANCE AND SAFETY IEMS'22.

Design and Manufacturing of Liquid Level Controller Based On Ultrasonic Sensor

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Published. April 15, 2022.

DOI: https://doi.org/10.58681/ajrt.22060103

Abstract. This paper provides an experimental liquid level controller, which is then one of the most routinely encountered control loops in the process industry. However, the most common level control configuration is an on/off valve triggered by a level sensor. Hence, determining tuning parameters for a liquid-level loop should probably be considered an engineering activity. In this context, a low-cost, height-performance prototype has been developed and manufactured in a laboratory-based on an ultrasonic sensor in process control. The principle is very simple, we will send sound waves from the sensor towards the liquid surface, the waves hit the surface, and comes back to the sensor, by measuring the time taken for the waves to hit the sensor we can calculate the distance between liquid surface and sensor. Moreover, a data acquisition card and control have been designed and successfully tested based on PIC16F877 microcontroller, and extremely robust, real-time, and multi-measurements have been achieved. In addition, a professional console in instrumentation has been used, and a code in the C environment has been developed to monitor and measure level progress using the LabView graphical programming language, which consists of three main subprograms and makes possible the following: manual control, control, data logger.

Keywords. Prototyping, Ultrasound, PIC16F877, Level and LabView, Lindustry process.

INTRODUCTION

An industrial production process includes the various activities and missions of a company leading to reach a finished product, in many industrial sectors, in pharmaceuticals, food processing or petrochemicals, but also in water treatment or biotechnology 5 (Khayan et al., 2022; Varvara et al, 2022). To ensure a good functioning and management of these industrial processes, the implementation of control systems is necessary. Moreover, industrial control systems monitor and automatically manage industrial processes (product distribution, handling, and production) and allow for human control. Furthermore, control systems help make the right decisions to maximize production with confidence, the control system simplifies operations and increases productivity with great control and integration capabilities (Khayan et al, 2019; Sergey et al., 2022).

Control is particularly important in the field of process engineering; in general, a closed-loop control system serves to set a predefined physical variable (regulating variable) to the desired value (setpoint) and maintain it at this value by measuring and adjusting the actual value.

In an industrial area, the most common parameters to control are level, flow, and temperature.

Liquid level measurement is a very important application in the industrial environment; there are several methods to measure liquid level. Here we will use an ultrasonic sensor to measure the liquid level in a tank. Surely this method is one of the best methods available for measurement of liquid level and the output is continuous as well. Figure 1 illustrates a typical process.

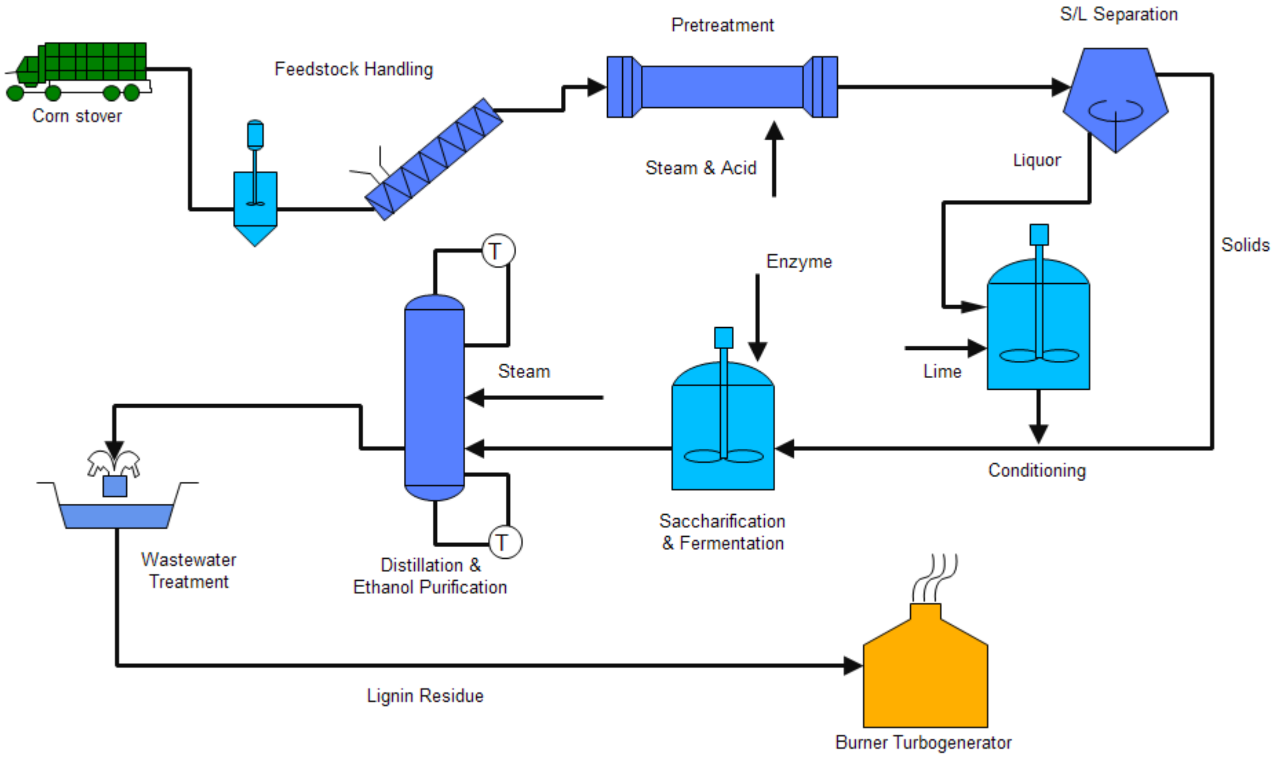

Fig.1. Typical process.

For the liquid level control loop, the On-Off method has been selected, which is very used and effective in the industry. Moreover, a Graphical User Interface as the human-machine interface has been designed to allow better graphical management. Finally, a prototype has been manufactured and tested in the laboratory, allowing a better simulation of the industrial environment.

PROCESS DIAGRAM

In this section, we present the most important parts, which are illustrated by the following block diagram including in particular: the industrial process and more specifically the unit controlled, the main block developed for data acquisition and control. Additionally, the physical data are also available in the Guide User Interface developed in the LabView environment, which allows switching the control of the unit in two modes: manual and automatic. In figure 2 we have presented an overview of the generic validation process.

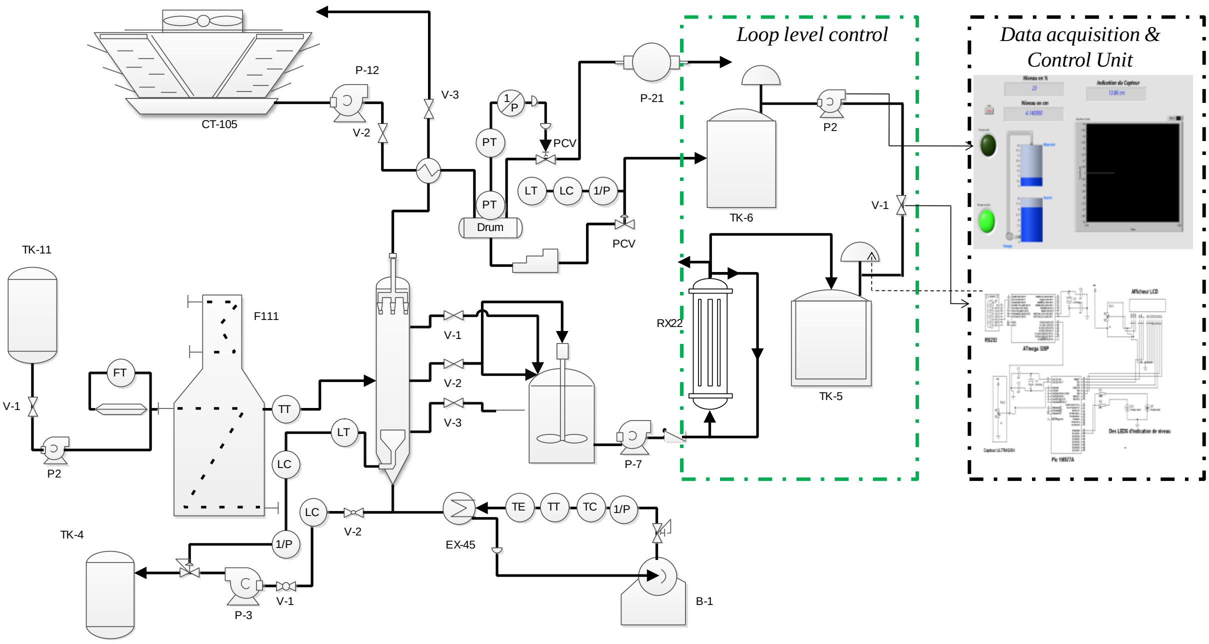

Fig.2. The controlled unit.

ENABLE TECHNOLOGIES

Microcontroller Selection and Programming

Selecting a microcontroller for an industrial application can be increasingly difficult with all the options available. However, the authors opted to use the PIC16F877 Microchip microcontroller, which features 256 bytes of EEPROM data memory, self-programming, an ICD, 8 channels of 10-bit Analog-to-Digital (A/D) converter, 2 additional timers, 2 capture/compare/PWM functions, the synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI™) or the 2-wire Inter-Integrated Circuit (I²C™) bus and a Universal Asynchronous Receiver Transmitter (USART). Figure 3 shows a schematic diagram of the PIC16F877.

Fig.3. Pins OUT diagram.

All of these features make it ideal for more advanced level A/D applications in automotive, industrial, appliances, and consumer applications.

Liquid level sensors

Recently, ultrasonic sensors are widely used in the level control loop. Moreover, are highly reliable methods, and offer several advantages such as non-contact, no clogging problem, and easy to calibrate. However, the principle is very simple as shown in figure 4. We will send sound waves from the sensor towards the liquid surface, the waves hit the surface and come back to a sensor, by measuring the time taken for the waves to hit the sensor we can calculate the distance between the liquid surface and sensor with dt, dm and di are: Distance between sensors and thank base, the distance between sensors and liquid surface and liquid level.

$$di = dt - dm \quad (1)$$

To measure the water level of the river/canal, the HC-SR04 ultrasonic sensor was used. This economical sensor provides 2cm to 400cm of non-contact measurement functionality with a ranging accuracy that can reach up to 3mm. in the same figure (in left); we present the reel photograph of the sensor. In addition, several works in the literature discuss the advantages of this measurement method (Putra et al., 2020; Konstantin et al., 2021).

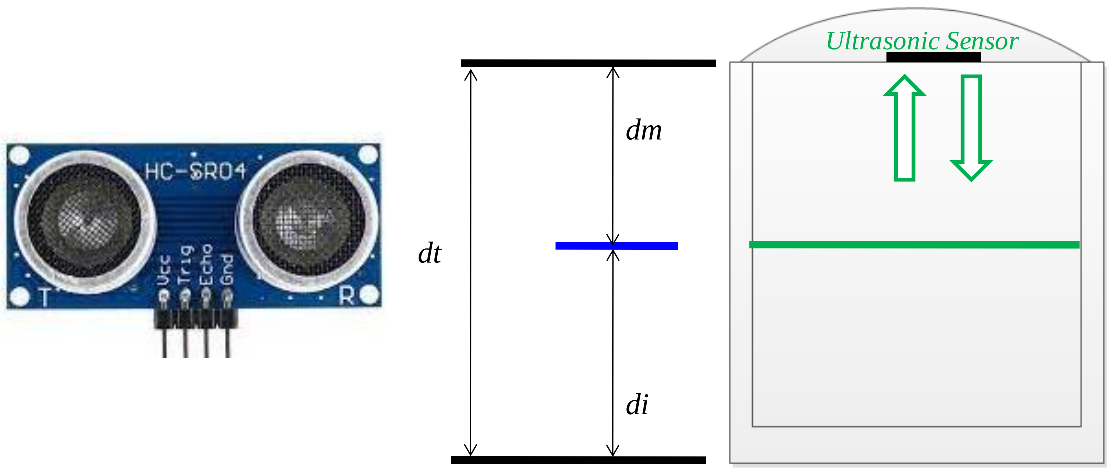

Fig.4. Pin diagram & Functioning principle.

Relay

An electronic relay is a switch that is operated with a low-power DC or AC voltage. The switch part is used to drive high power loads such as pumps. However, the relay used in this study is controlled by a voltage of 5 V generated by the microcontroller. The standard electric scheme is done in figure 5.

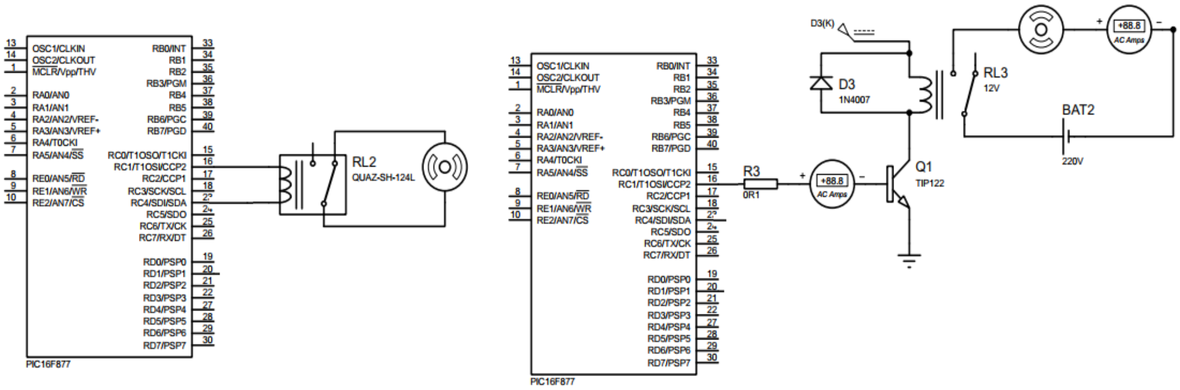

Fig.5. Relay electrical diagram.

TEST, INTEGRATION, AND VALIDATION

Microcontroller

Peripheral Interface Controllers (PIC) is one of the advanced microcontrollers developed by microchip technologies. Figure 6 shows the block diagram of a PIC microcontroller-based digital outputs application. Here, a LED is connected to the microcontroller as illustrated in figure 6 using an external pin. However, this configuration is suitable for a quick functionality test.

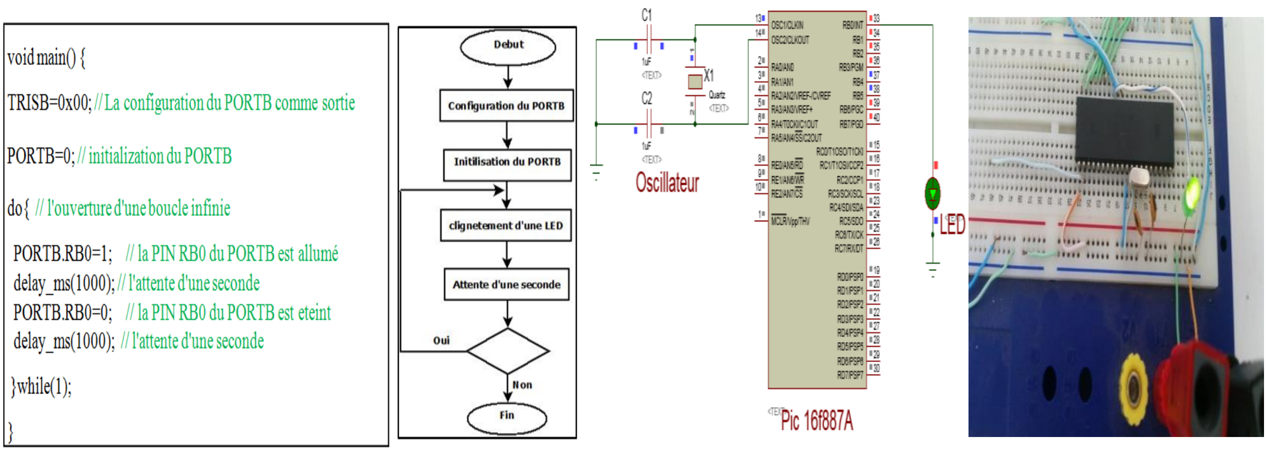

Fig.6. Electrical assembly and test of PIC16F877.

Furthermore, the PIC microcontroller programming is done by the embedded C language using PICFlash software, this software allows programming support link and PC thought serial port.

LCD Display

These tests series aim to provide easy and practical examples that anyone can understand. In the previous test, we have seen how to use digital outputs configuration in PIC16F877A. In this experiment, we will practically demonstrate the assembly and LCD Interfacing with PIC16F877A.

Figure 7 shows the schematic diagram, also the simulation, and the experimental results.

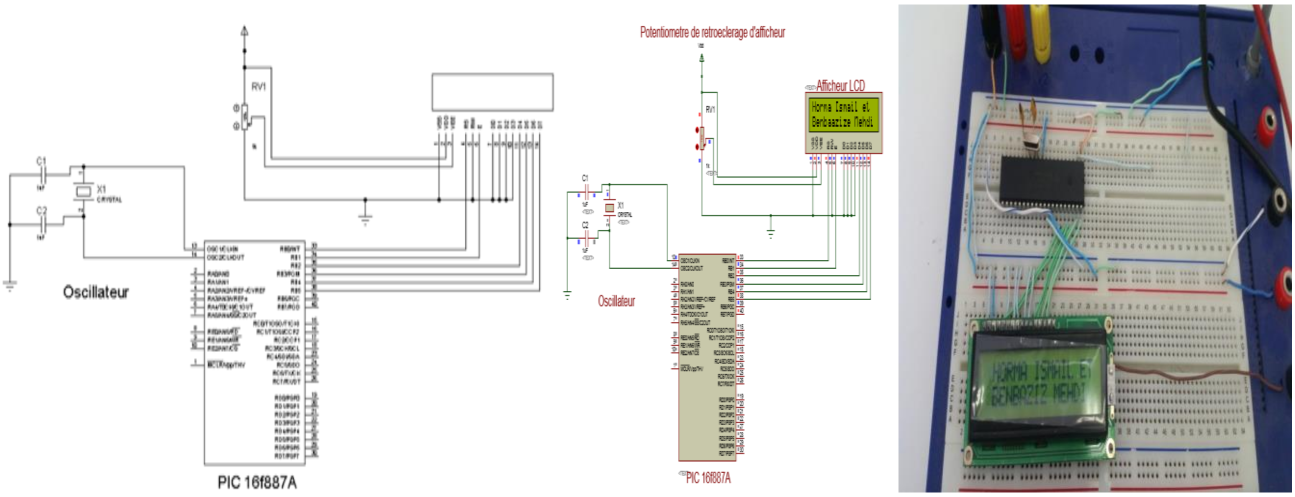

Fig.7. LCD test.

Analog/Digital Converter Module

Analog-to-digital converters are essential building blocks in modern electronic systems, already used as an intermediate device to convert the signals from analog to digital form. For our study, we repeated these tests and used them in ultrasonic data acquisition. However, to illustrate this, a flowchart describing the steps taken is provided in figure 8.

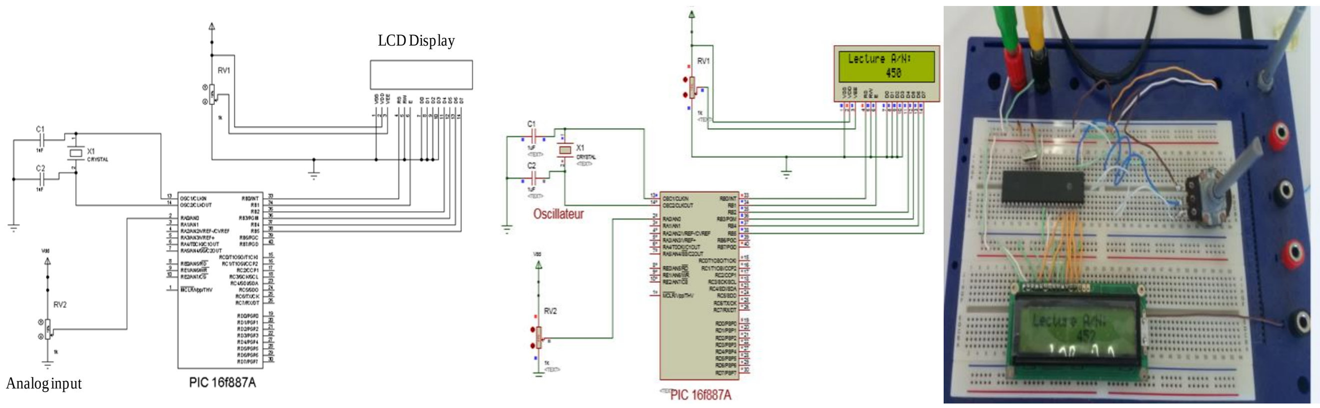

Fig.8. ADC implementation.

It will provide experimental results from which the parameters needed for the sensors can be derived. This test, therefore, shows us that the PIC programmer that was used is working correctly, the experimental results show the validity of the approach and its robustness concerning calibration errors.

HC-SR04 test

In this subsection, the test results presented here are achieved to check the correct functioning of the HC-SR04 module with a PIC 16f877 microcontroller, and some C code. Figure 9 schematically illustrates the sensor wiring and connection. However, the results achieved in the phase are known to increase functioning in many scenarios.

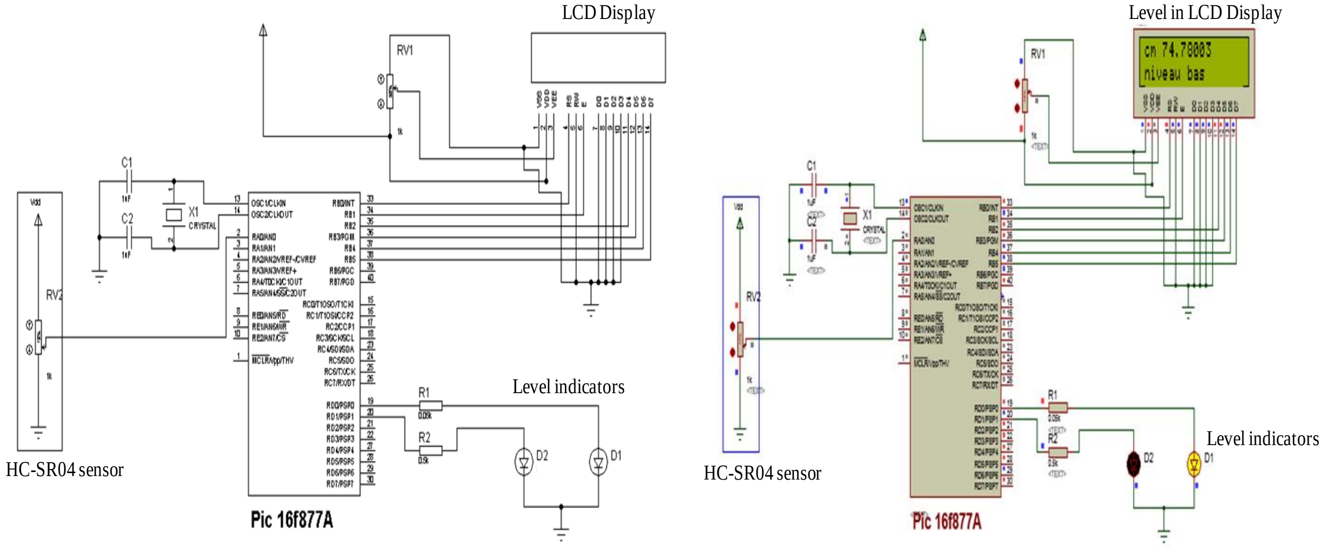

Fig.9. HC-SR04 electrical diagram.

Furthermore, as shown in figure 10 below included the serial RS232 interface, a broad range of outputs has already been produced. The results therefore clearly demonstrate that the suggested approach to resolving this liquid level measurement problem is given satisfactory results in terms of precision and reliability.

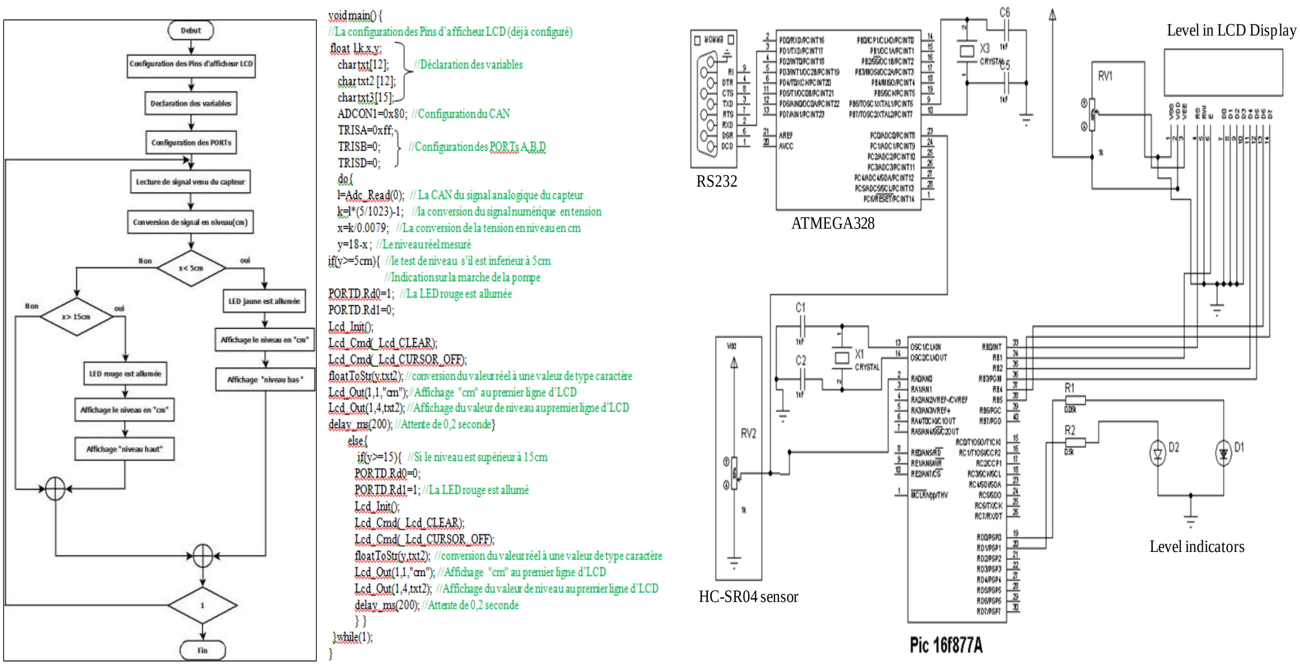

Fig.10. Serial interface.

DATA CONTROL AND MONITORING

The monitoring data and the control process are always ensured by the graphical user interface. However, (GUI) is essential to an industrial application, is a type of user interface that allows users to interact with graphical icons and visual indicators and makes recovery easy even for the non-technical person. In literature, the most advanced software and continuously add features and improving interfaces is LabView, which is a system-design platform and development environment for a visual programming language from National Instruments (Kishan, 2021; Eardprab and Pumpoung, 2021)). As part of this project, computer programs in LabView have been written and adapted to acquire the data coming from the HC-RS04 sensor. The whole system is being automated using LabView. Figure 11 presents a summary of all loops developed for the fundamental panel of our application from measurements/control and data transmitted to a computer.

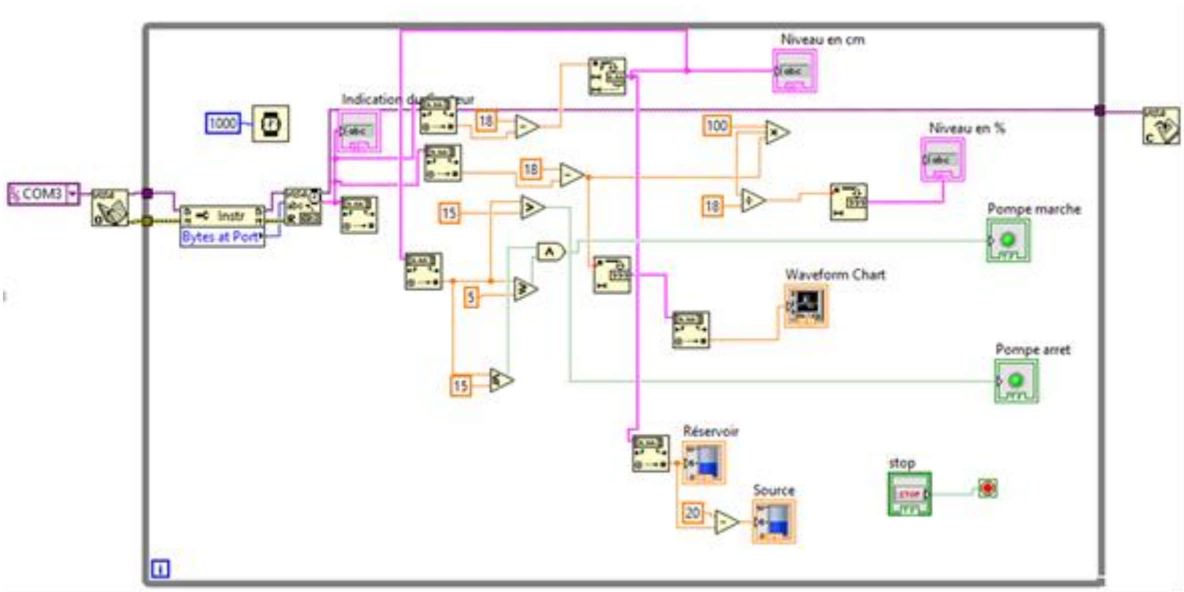

Fig.11. LabView panel.

Included with the board is also a LabView program, which will do the calculations as well and display the actual liquid levels in the different thanks. The reel results obtained from these measures are shown in figure 12.

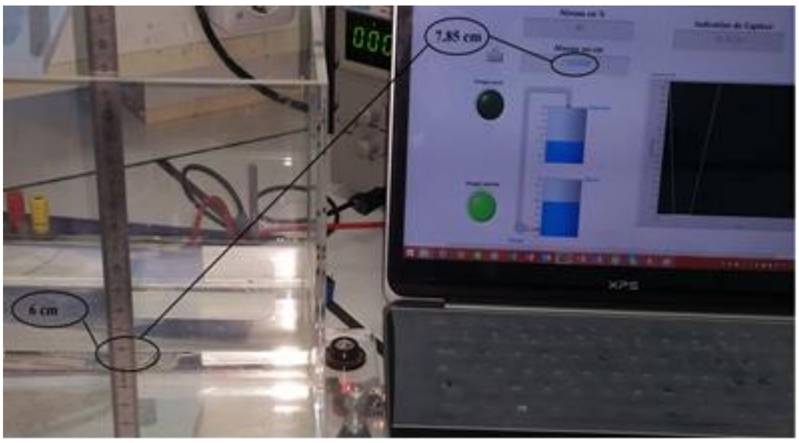

Fig.12. Reel measurements.

The main purpose of this step is to ensure that the measures taken are relevant and robust. Based on these initial analyses, two scenarios have been projected to take into account the reliability: the first is a Low-level indicator and the second is Height level indication in red led color.

It is more important, as figure 13 makes clear, the exactitude and the real-time response of the system.

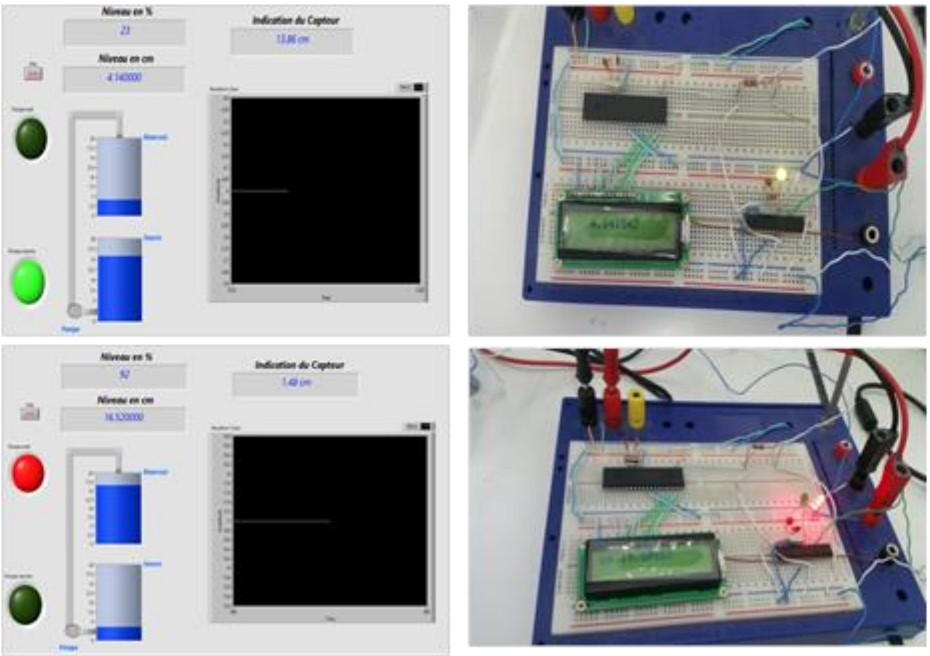

Fig.13. Liquid level and data update rate.

Finally, in figure 14 below, we present a test bench carried at the laboratory included: two power supplies (12 V for relay and 5V for PIC microcontroller), a liquid thank with HC-SR04 module, and a computer for data/control processing.

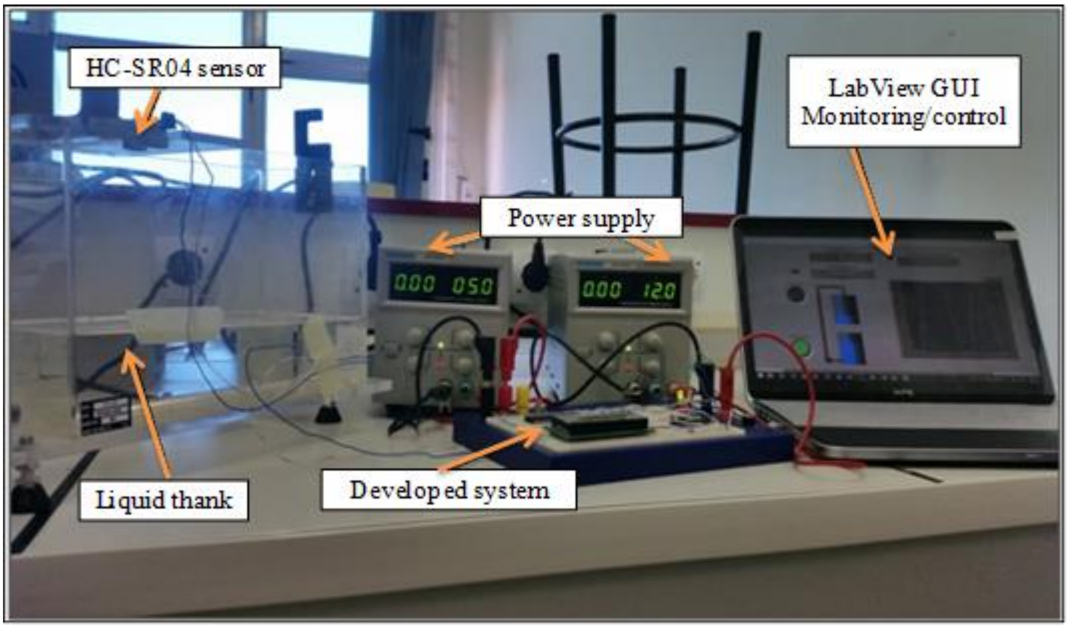

Fig.14. Test bench.

CONCLUSION

This study proposed the design and the development of a liquid level measurement' and control for industrial thanks. Moreover, the HC-SR04 sensor was used as the ultrasonic detector to measure the level of water in real-time. This information was captured by the PIC16F877 microcontroller, where it was transmitted and published to the computer. Thus, the integrated use of the PIC microcontroller in the data sampling through the digital-analog converter provided good and fast measures; as a consequence, the sensitivity was improved. However, these features make the proposed tests bench attractive for quality control analysis that involves liquid level measurements and two modes: manual and automatic control.

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