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Didactic System For Level Control Of A Water Tank

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ABSTRACT-

This document presents in a didactic way the elaboration of a water tank level control system using a PSoC5LP, which includes an alphanumeric LCD, an ultrasonic sensor, a matrix keyboard (to enter the desired level by the user in centimeters), two small motor pumps and additional components to generate the filling and emptying of the water tank. For the visualization of the information generated by the system, the alphanumeric LCD is used. The PSoC5LP internal timers are used to measure the level display generated by the ultrasonic sensor, to update the data on the LCD and to control the keypad. The measurements captured by selecting different levels (water heights) were verified and compared practically. With the above, the objective of showing practically the use of timers, the concept of interruption and various elements associated with the teaching of microcontrollers and specifically the PSoC5LP would be fulfilled.

Keywords: Interrupt, LCD, PSoC5LP, Ultrasound, Timer

I. INTRODUCTION

To show the operation of the display through the LCD block, the internal timers and the interruptions offered by the PSoC5LP, this document shows the design of a water tank level control system (since the system is didactic, the storage tank was implemented with plastic soda bottles), in which it is also necessary the use of external peripherals such as the 4x4 matrix keyboard and the HC-SR04 ultrasound sensor.

Timer

The Timer module (Figure 1) allows time interval measurements to be taken either by using software or by interrupting the component.

At the end of the configured time period, the Timer generates a signal at the output of the block. For this, the period or time in which the signal is to be manipulated must be configured and the clock frequency must also be specified so that the definition of the time period is consistent (Cypress, 2015).

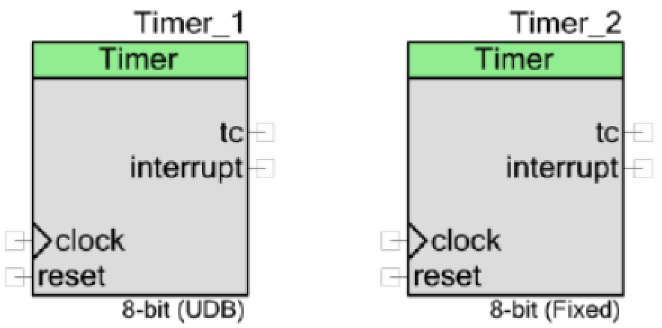
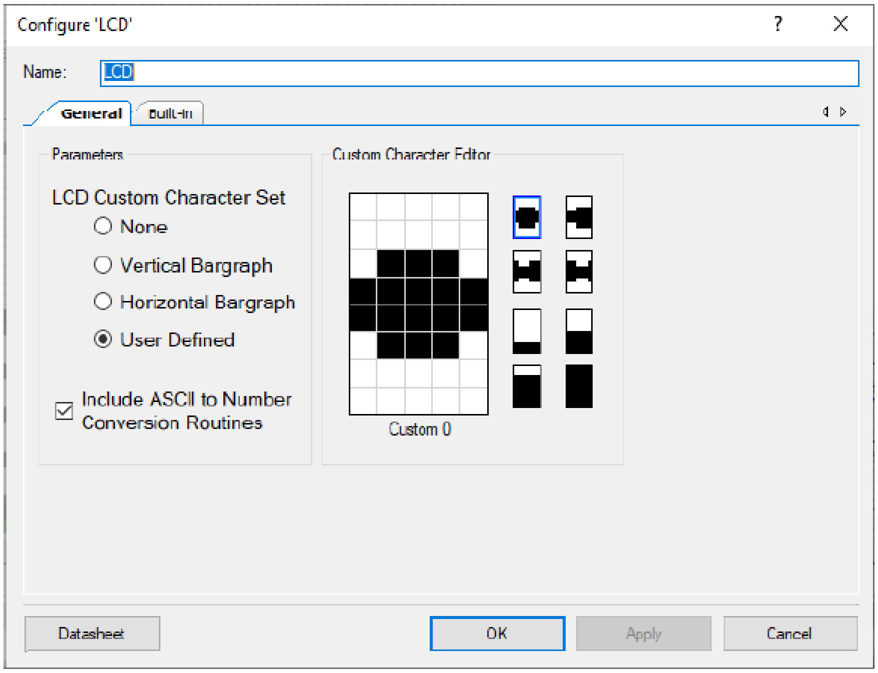


Figure 1: UDB Timer and Fixed Function (FF) Modules

Character LCD

It is a component that implements the industry-standard Hitachi HD44780 display LCD (Camargo & Perdomo, 2016). This component contains a set of library routines that enable the use of one-, two- or four-line LCD modules that implement the Hitachi 44780 4-bit standard (Cypress, 2017).

In Figure 2 you can see the configuration that was performed on the LCD, in this case, some defined figures were used to generate a filling animation in the tank.



Configure 'LCD'

Name: LCD

Parameters

LCD Custom Character Set
○ None
○ Vertical Bargraph
○ Horizontal Bargraph
● User Defined

☑ Include ASCII to Number Conversion Routines

Figure 2: Character LCD Component Configuration

Interrupts

They are resources or mechanisms of the microcontroller to respond to events immediately, allowing to temporarily suspend the main program to run an interrupt service subroutine ISR (Interrupt Service Routine), when it ends it resumes the execution of the main program.

These interrupts are generated when peripheral devices connected to the PSoC5LP, generate a state change in its terminals or generate a software signal indicating that it wants to send information to the microcontroller, this can occur asynchronously (Reyes & Cid, 2015).

An interrupt can be defined as a signal generated by the hardware or a software instruction that forces the CPU of the device used, to stop the execution of the program being executed (main program), to execute a routine, procedure or function that is considered as a priority and whose execution must be performed at the time the request is made (Camargo, 2013).

The following types of interrupts are available:

- External HW: they are asynchronous to CPU execution, they are linked to input or output devices.
- Internal HW: they are linked to internal devices of the PSoC5LP such as Interrupts generated by time counting.
- SW: Software interrupts, they are generated by a running program.

Ultrasonic sensor HC-SR04

The ultrasonic sensor is typically used to measure the distance of objects, as its name suggests, it sends out bursts of ultrasound which bounce off nearby objects and return to the origin. The time elapsed between the moment the ultrasound burst is sent and it returns is the one that indicates through an equivalence, the distance of the object. In theory, its operating range is between 2 cm and 400 cm with a resolution of 0.3 cm, but in practice, the optimal operating range is between 10 cm and 250 cm (Camargo, Perdomo & Bermudez, 2019).

Figure 3 shows the image of a low-cost commercial ultrasound sensor reference HC-SR04 (Sparfun, 2019), where the ultrasound emitter and receiver are separated.

Figure 3: Ultrasonic sensor HC-SR04

As shown in the timing diagram in Figure 4, the sensor is very simple to use. Externally, the user applies a trigger pulse on the Trigger pin of 10us minimum duration, which starts the sequence. The module transmits a train of pulses or burst of 8 cycles at 40KHz. At that moment the output signal of the Echo pin goes from level '0' to level '1'. When the receiver receives the transmitted signal as a result of bouncing off an object (echo), this output goes back to level '0'. The user must measure the pulse duration of this signal, i.e. the time the echo signal remains at '1'. For the module to stabilize, a time-lapse of at least

20mS must be left between the moment when the echo signal goes to '0' and a new trigger pulse that starts the next cycle or measurement, this allows measurements to be taken every 50 mS.

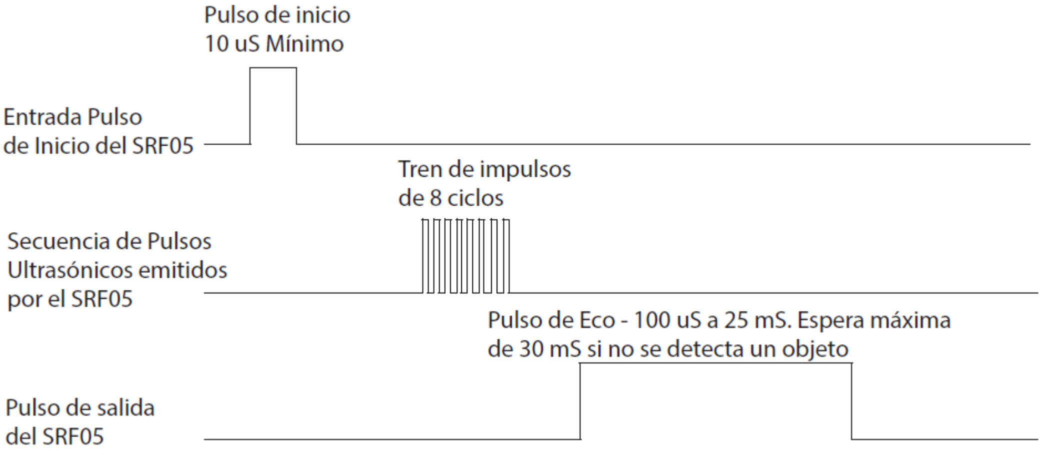


Figure 4: Timing diagram of an ultrasonic sensor (Camargo, Perdomo & Bermúdez, 2019)

The duration of the output echo pulse varies between 100uS and 25mS, depending on the distance between the module capsules and the object. The speed of sound is 29.15us/cm which, since it makes a round trip, is set to 58.30us/cm. Thus, the minimum range that can be measured is 1.7 cm (10us/58) and the maximum range is 431 cm (25ms/58).

II. PROBLEM FORMULATION

Design and implement with the PSoC5LP a water tank level control system (Alotaibi, Balabid, Albeladi & Alharbi, 2019) using an ultrasonic sensor. Using a 4x4-key matrix keyboard, the desired level (which may vary from 1 to 25cm) will be selected. The measured distance will be displayed on an LCD (information of the desired height and the current height measured by the control system), the system will measure in centimeter units (the resolution of the system will be 1cm), the data on the LCD will be updated once per second. The necessary elements will have to be included to automatically fill or empty the system when necessary according to the selected level (Jiang, 2021).

In this case, there were two tanks (Figure 5), connected by hoses. In the case of filling and emptying one of the tanks, two small motor pumps were used, one for filling and the other for emptying one of the tanks. In addition, one of these tanks is the one of interest and therefore its liquid level was controlled using the HC-SR04 ultrasonic sensor, which is located in the upper part of the tank.

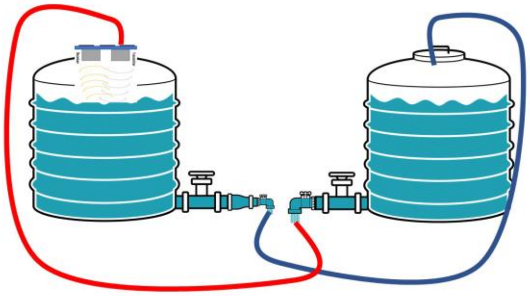


Figure 5: Tank to be monitored with the sensor on the left, reservoir tank on the right

III. DESIGN AND SOLUTION MODEL

Hardware

To solve the problem, we start by analyzing the necessary hardware and software components. Thus, if you have a 16x2 LCD, it is evident the use of the LCD block of the PSoC5LP allows its configuration. The ultrasound sensor works by sending bursts of ultrasound which bounce off nearby objects and return to the origin, therefore, the time elapsed between sending the burst until it returns must be measured; for this reason, a Timer block is implemented to time and soon find the equivalence of distance.

All the peripherals and components used in the software will be explained and detailed below. Figure 6 shows the circuit diagram and connections of the peripherals with the proposed solution.

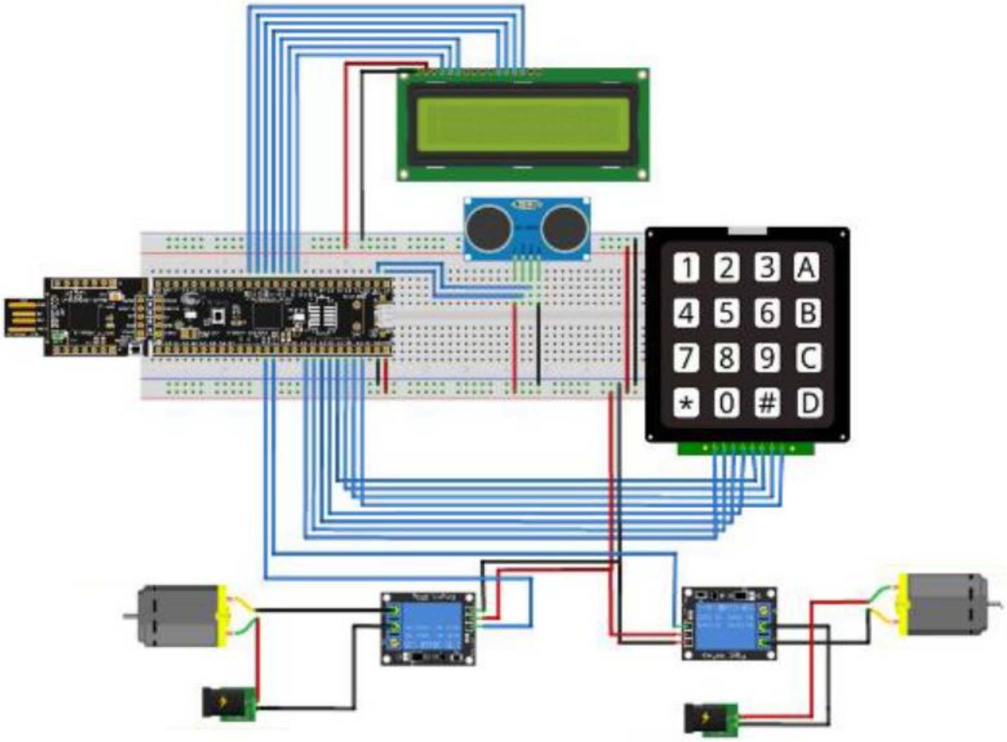


Figure 6: Wiring diagram

Figure 7 shows the physical implementation of the proposed circuit diagram. There it is possible to visualize the model that was made using a large soda bottle, approximately 30 cm long since it is a requirement that the system varies its size between 1 and 25 centimeters. Inside the container, there is the first motor pump (Emptying) and behind the container, there is a second container that is in charge of supplying or storing the water from the first container, thanks to a second motor pump (Filling). In the upper part, it is possible to observe the ultrasonic sensor, coupled to the container nozzle.

Figure 7: Implemented prototype

Software

The algorithm to solve the problem is implemented in the PSoC5LP memory, based on the circuit diagram shown in Figure 8, generated by the PSoC Creator, which is the development environment used to work with PSoC5LP.

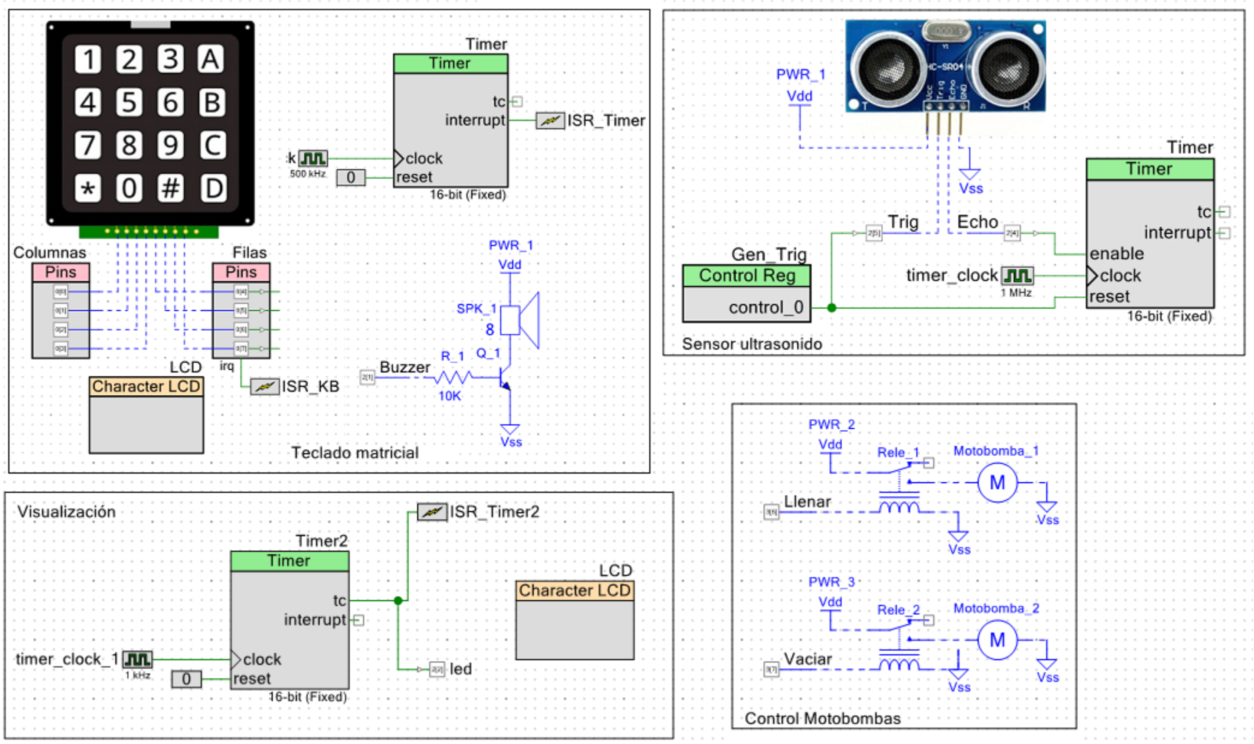


Figure 8: Circuit diagram with a proposed solution to the problem

The Timer block for the ultrasound sensor named Timer has the following configuration: the Resolution parameter with the value 16-Bit selected, Implementation with the Fixed Function option selected, Period 65535 to perform 1us counts with the frequency of the timer_clock block set to 1MHz with a 1% tolerance. The Capture Mode parameter with None selected, Enable Mode with Software and Hardware selected, Run Mode in Continuous mode, and hardware interrupts disabled.

A Control_Reg block named Gen_trig is connected to the reset input of the Timer block, which in this case is in charge of sending an internal logic value '0' or '1' to generate the trigger signal of the ultrasound sensor and reset the Timer counter since in the Outputs configuration option the value 1 was selected. The enable input of the Timer receives the echo signal from the sensor, enabling the Timer when the time measurement process is started and disabling it at the end of the measurement.

The LCD must be updated every one second, so a second timer (Timer2) with a 1KHz clock is included to have a period of 1s. Figure 8 also shows an output pin with led name connected to the tc signal of Timer2, this to verify by hardware, that the interruption is being generated every second and therefore that the information on the LCD is being updated

Finally, to drive the electric pumps, two pins called Vaciar andLlenar are used, both digital output pins in strong drive mode, enabled for software use, with the terminals extended to make the corresponding diagrams. Because the signal goes first to a PNP type BJT and this must be operating as an open circuit for the base of the next transistor to see zero volts and be inactive, then the high-level corresponding to about 5 volts is set on the pin and is equal to that of the bias, and so the pump is inactive. For the motor pumps to be inactive, the initial value must be a logical one

The flowchart in Figure 9 shows the algorithm of the in the main function the interrupts are enabled, the LCD and the timers are initialized, but the sensor timer is stopped because it should generate the count only when the ECHO is high and it is not yet the case, then each interrupt is enabled and the name is given and later the body is created, that is, the code to be executed. The code initializes all variables to zero and prints on the screen the corresponding indications of the level you want to enter and custom characters that correspond to the animations of emptying and filling the tank.

To manage the sensor, the code is segmented into two parts. The first is in the main function (Figure 9), in the repetitive process, first check the status of the ECHO pin and if it is low, gives a time of 50ms, waiting time between one measurement and another, recommended by the manufacturer, then set the Trig pin to a logic one, wait 10ms, and set it to logic zero, At the end of this section the data is converted from microseconds to distance in millimeters by applying the equations given by the manufacturer shown in the section Ultrasound Sensor HC-SR04, and by subtracting this distance from the height of the sensor, the liquid level in millimeters is obtained.

When it is one, it enables the sensor timer and starts counting, and when it is zero because the counting is done in a descending way, it captures the number of the count in which it was left, subtracting it from the number with which it was configured, 65535 in this case, thus obtaining the time in microseconds and saves it in the variable t, loads the counter again with 65535 and stops it being ready for the next measurement, and finally, clears the interrupt, allowing to call this function again when any change of state in the ECHO occurs.

For the function AnimationHeight() first, the height is sectioned into eight parts which correspond to 30mm for each one and then depending on the height and through a repetitive process and a variable is called three times a function called CharactersHeight(m) and the number of the section in which it is located, if:

- d < 150 prints spaces in the top row and the character according to the level in the bottom row.
- d > 120 prints the full character in the bottom row and the character according to the corresponding level in the top row.

As they are bits six and seven, then it is incremented by 64 to make the count only with those two bits, and finally, those two bits are cleared to leave them ready for the next use.

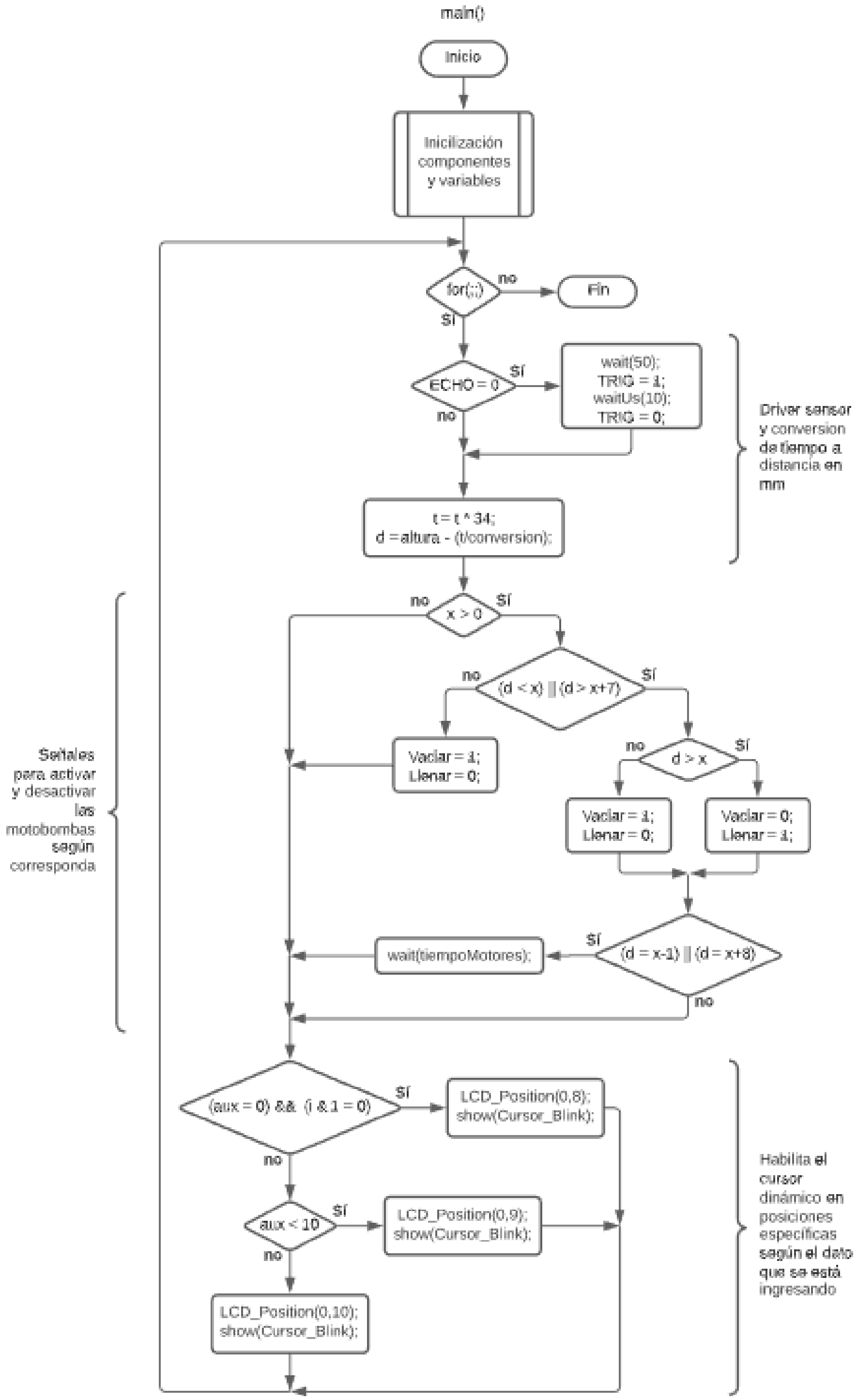


Figure 9: General flow diagram

IV. RESULTS

Initially, the ultrasonic sensor is positioned at the top of the tank without water, to obtain the container measurement data and assign it to the code already shown.

Once this value is added to the code, the tank is filled manually, with an initial level of 14 cm, and the desired height is entered (20 cm for the test). To enter the data, first, enter the desired number and press the "A" key, which displays the number entered and the implemented design starts to drive the respective motor pump. For the first test, as the current level was lower than the one entered, the filling motor pump is activated until the current level and the one entered are equal. The system presents a good approximation between the distance measured by the sensor and the tape measure, for this first data acquisition, the difference between one measurement and the other is of millimeters, even less than 5 mm distance.

For the second test, we start from the previous measurement (20.3 cm) and now we ask the system for a level of 10 cm. Now the system must empty the tank, therefore, the active motor pump must be in charge of emptying the container. The system fulfills its function, the tank is emptied, however, it is notorious for the increase in the gap between the measurements taken by the sensor and those verified by the tape measure. Despite this increase, the system remains within the established parameters, the measurement error is still less than one centimeter, but this time greater than 5 mm.

The last test is performed, this time, a level of 18 cm is required, starting from the previous level. Once again the measurement is verified, obtaining a measurement of 18.3cm. Again it is possible to observe how the system fulfills its task and gives quite acceptable results. The accuracy of the system improves notably, presenting an error of less than 5 mm of distance.

Table 1 shows the results obtained from the various measurement levels selected for the tests.

Table 1: Results obtained from the measurement of the control system

Required sensor measurement (cm)	Actual required measurement (cm)	Error(%)
2	2.2	10
5	4.6	8
7	6.5	7.1
10	10.6	6
14	13.2	5.7
17	16.5	2.9
18	18.3	1.6
20	20.3	1.5
25	25.4	1.6
28	27.5	1.8

V. CONCLUSIONS

The liquid level control for a tank and all that this entails is obtained, each of the requirements is fulfilled and the operation of each component used is internalized, thus fulfilling the initial objective of showing this type of control systems in a didactic way.

Regarding the measurements obtained, a fairly accurate system is obtained, which meets the requirements set out in the initial problem, because if the respective parallel between the measurements captured by the ultrasonic sensor and the actual measurements, errors ranging from 1.5% to 3% are obtained, for levels greater than 15 cm. For slightly smaller values, the increase in the measurement error is notorious, presenting an error that varies from 5% to 10%. However, this does not mean that the system is working incorrectly, since the maximum permissible error value is 10%, i.e. 1 cm difference between measurements. These error values can be supported, among many other causes, by the temperature and the way of measurement; irregularities in the container used since in this case the bottom are not flat and the motor pumps, which could influence the data acquisition by the sensor.

REFERENCES

1. Alotaibi, M., Balabid, M., Albeladi, W. & Alharbi, F. (2019). "Implementation of Liquid Level Control System," 2019 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS).
2. Camargo, J. R. (2013). Guía de Operación y Aplicaciones Prácticas de los Microcontroladores Freescale. (First Ed.). Bogotá: Ed. Universidad Distrital.
3. Camargo, J. R. &Perdomo, C. A. (2016). Introducción al PSoC5LP: Teoría y aplicaciones prácticas. (First Ed.). Bogotá: Ed. Universidad Distrital.
4. Camargo, J. R., Perdomo, C. A. & Bermúdez, B. (2019). Proyectos prácticos con PSoC5LP. (First Ed.). Bogotá: Ediciones de la U.
5. Cypress Semiconductor Corporation. (2017). Timer 2.80. [Online]: Retrieved on 15-May-2021, at URL: https://www.cypress.com/file/376411/download
6. Cypress Semiconductor Corporation. (2015). Character LCD 2.20. [Online]: Retrieved on 15-May-2021, at URL: https://www.cypress.com/file/220301/download
7. Jiang, P. (2021). “Summary of PID Control System of Liquid Level of a Single-Capacity Tank,” 2021 International Conference on Advances in Optics and Computational Sciences
8. Reyes, F. & Cid, J. (2015). Arduino – Aplicaciones en Robótica, Mecatrónica e Ingenierías. (First Ed.). Alfaomega Grupo Editor
9. Sparfun. (2019). Ultrasonic Ranging Module HC - SR04. [Online]: Retrieved on 18-May-2021, at URL: https://cdn.sparkfun.com/datasheets/Sensors/Proximity/HCSR04.pdf