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Development of an application for monitoring the level of a fluid, using a cell phone, Bluetooth communication and Arduino platform

Desarrollo de una aplicación para el monitoreo del nivel de un fluido, utilizando un teléfono celular, comunicación Bluetooth y plataforma Arduino

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Abstract

The measurements of fluid height level in different situations such as in cisterns, tanks or wastewater tanks, are important but involve difficulties and precautions taken by the user to avoid possible falls or inhale toxic vapors; the present project has the purpose of measuring the height level of the fluid using an ultrasonic sensor, also integrating the Arduino Mega platform as an information processing and monitoring system, as well as a Bluetooth wireless communication circuit, in order to transmit the information obtained to a smartphone type cell phone, agile safe and reliable. The tangible benefits of the project, in addition to the security it will offer the user, are the economic ones, based on low cost components compared to the products of industrial brands. Finally, this project can be integrated as part of others related to renewable energies and industrial processes, which require measurements of the level of various liquids.

Arduino Mega, Bluetooth, Ultrasonic

Resumen

Las mediciones de nivel de altura de fluidos en situaciones diversas como son en las cisternas, tanques o depósitos de aguas residuales, son importantes pero conllevan dificultades y toma de precauciones por parte del usuario para evitar posibles caídas o aspirar vapores tóxicos; el presente proyecto tiene la finalidad de medir el nivel de altura del fluido utilizando un sensor ultrasónico, integrando también la plataforma Arduino Mega como sistema de procesamiento de información y monitoreo, así como un circuito de comunicación inalámbrica Bluetooth, para poder transmitir la información obtenida a un celular tipo Smartphone de manera, ágil segura y confiable. Los beneficios tangibles del proyecto además de la seguridad que ofrecerá al usuario, son el económico al basarse en componentes de bajo costo, este proyecto puede integrarse como parte de otros relacionados con las energías renovables y los procesos industriales, que requieren mediciones del nivel de diversos líquidos.

Arduino Mega, Bluetooth, Ultrasónico

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Introduction

The measurement of one variable and consequently the calculation of others is important in many industrial processes, which is why it is proposed in the present project the quantification of the height of the level of a fluid, in this case water contained in an exprofeso container for it and from this quantification calculate the volume of liquid and the percentage of filling with respect to the maximum capacity considered.

The measurement of the height of the fluid level will be made using a low cost ultrasonic sensor, an Arduino Mega card as a control platform, a Bluetooth module for wireless communication and an application app designed, created and installed on a Smartphone type phone and so on to have a remote monitoring of the three important variables to know: height of the fluid level, volume and percentage of filling.

Objective

Development of a low cost experimental prototype that allows the measurement of the height of a water level, calculating additionally the volume of the fluid and the filling percentage; these variables being monitored remotely with a smartphone via a Bluetooth link.

Development

Materials and characteristics

Below is a list and brief description of the materials to be used in this project.

1 Ultrasonic sensor HC-SR04, integrated in a PCB with four terminals to connect, this will be powered and connected by means of the Arduino Mega Card

The HC-SR04 sensor is an excellent choice as an ultrasonic distance sensor. Its cost / benefit ratio makes it optimal for a wide range of applications. The use of this module is quite simple because all the control, transmission and reception electronics are contained in a PCB. The user should only send a trigger pulse and measure the time at high of the response pulse. Only 4 wires are required to complete the interface with the **HC-SR04** sensor module.

The **HC-SR04** is compatible with most microcontrollers on the market, including the Arduino UNO, Arduino MEGA and other compatible cards that work with 5 volts. There are libraries for this module that make the part of the software is solved in a very simple way.

Main features of the HC-SR04 Ultrasonic distance sensor:

– 5 volts power
– Simple interface: Only 4-wire Vcc, Trigger, Echo, GND
– Measuring range: 2 cm to 400 cm
– Supply current: 15 mA
– Pulse frequency: 40 KHz
– Ultrasonic pulse opening: 15º
– Trigger signal: 10 µs
– Dimensions of the module: 45x20x15 mm.

(GEEK FACTORY, s.f.)

Figure 1 Ultrasonic sensor HC-SR04 Top view
Source: www.google.com

Figure 2 Ultrasonic sensor HC-SR04 Bottom view
Source: www.google.com

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1 Arduino Mega Card, is an open-source development card built with an Atmega2560 microcontroller that has input and output (I / O), analog and digital pins. This card is programmed in a development environment that implements the Processing / Wiring language. Arduino can be used in the development of autonomous interactive objects or can communicate to a PC through the serial port (conversion with USB) using languages such as Flash, Processing, MaxMSP, etc. The possibilities of carrying out Arduino-based developments are limited to the imagination. The Arduino Mega has 54 digital input / output pins (14 of which can be used as PWM outputs), 16 analog inputs, 4 UARTs (serial hardware ports), 16MHz crystal oscillator, USB connection, power jack, connector ICSP and reset button. Arduino Mega incorporates everything necessary for the microcontroller to work; simply connect it to your PC by means of a USB cable or an external power supply (9 up to 12VDC). The Arduino Mega is compatible with most of the shields designed for Arduino Duemilanove, diecimila or UNO.
(Chile), s.f.).

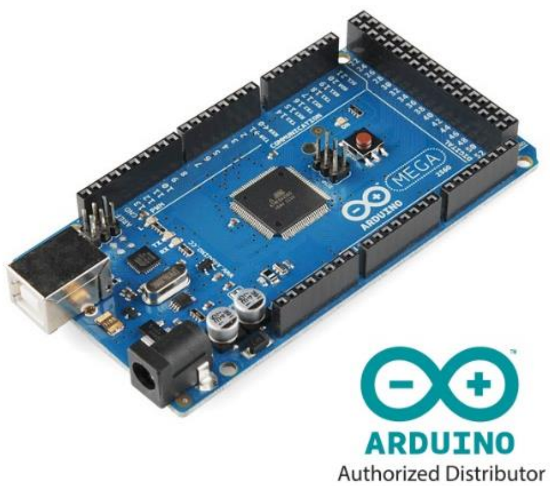

Figure 3 Arduino Mega
Source: www.google.com

1 **Bluetooth module HC-05,** which will allow communication between the Arduino Mega card and the resident app on a Smartphone-type phone, via Bluetooth. The module of Bluetooth HC-05 is the one that offers a better ratio of price and characteristics, since it is a Master-Slave module, it means that in addition to receiving connections from a PC or Tablet, it is also capable of generating connections to other devices Bluetooth This allows us, for example, to connect two Bluetooth modules and form a point-to-point connection to transmit data between two microcontrollers or devices.

(GEEK FACTORY, s.f.)

Figure 4 Módulo HC05
Source: www.google.com

1 **LCD display 16x2 model LMG-16D2T,** which will allow an information display locally, specifically: height of the fluid level and the calculated volume thereof.

Figure 5 Display LCD 16x2
Source: www.google.com

1 **Unicel sphere** 4 cm in diameter, used as a float (option 1) and lined with aluminum foil.

1 **Cylindrical cork disk** of 4 cm diameter by 2 mm thickness, also used as a float (option 2), this is aluminum foil lining.

1 **PVC tube** with an approximate length of 40 cm and an inside diameter of 2 inches. The aforementioned tube will contain the float inside and at one end it will have placed the ultrasonic sensor.

1 **Cylindrical plastic container** of approximately 19 liters capacity, this container will serve as a water container.

1 **Phone type Smartphone** where the application will be created and installed, to establish communication with the level measurement system and receive information to be monitored in real time.

1 **Power supply** 12 VDC / 2 A, to power the Arduino Mega card, which in turn will provide power to the ultrasonic sensor, Bluetooth module and LCD Display.

1 **Small water pump,** which will serve to fill or drain the water in the plastic cylindrical bucket.

Theory

Ultrasound sensors are very useful for measuring distances and detecting obstacles.

The operation is simple, it sends an inaudible ultrasonic signal and gives us the time it takes to go back and forth to the nearest obstacle that it detected.

Generally they are formed by two cylinders placed side by side, one of them is the one that emits the ultrasonic signal, while the other is the one who receives it, it is a very simple system but it does not stop being effective.

The HC-SR04 sensor in particular has a very good sensitivity of the order of 3 mm, taking into account that most of the applications where this sensor is used is to measure or detect obstacles or distances greater than several centimeters, we can say that its sensitivity is very good.

The HC-SR04 sensor counts the time that elapses between the emission and the reception of the ultrasonic signal, clearly we can deduce that the time is dependent on the distance, the signal will take longer to go and return if the object is far away than if it is close.

Recalling some basic physics equations we know that **d=v*t** (the distance traveled is equal to the speed of the object in motion for the time it takes to arrive).

We have the time, but what is the speed of the signal? To answer that question we have to be clear that the sensor emits an ultrasonic signal and it travels at the speed of sound, at approximately 340 m / s (meters / second). If, for example, the HC-SR04 sensor gives us a reading of 1,003 ms (milliseconds) and we apply the above formula, we have left;

$$d = 340\frac{m}{s} * 1.003\,ms = 0.341m \qquad (1)$$

meters, but since this time is the round trip, the real distance to the object will be half, that's why we divide the result between two, which gives us a final result of 0.170 meters (ie 17 cm or 170 mm).

Obviously the sensor alone is not much use, we need a microcontroller to read the data that gives us and perform the relevant calculations, if what we want to develop is practical, no doubt that the best option we can choose is the Arduino platform.
(etools, 2018)

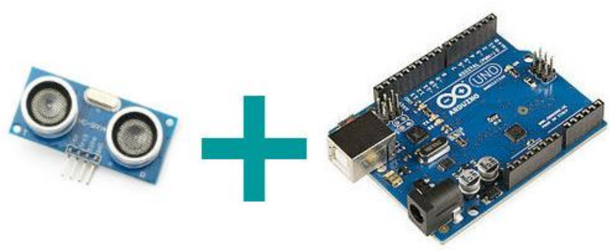

Figure 6 Ultrasonic Sensor + Arduino
Source: www.google.com

Physical Implementation

First, it was conceptualized that the measurement of the height of the water level of a fluid (specifically in this case clean water "from the tap"), would be made by measuring the distance of the float contained inside a PVC tube with respect to the sensor ultrasonic placed on one end of the tube, knowing this distance you could calculate the height of the water column. For this it is important to mention that they were tested as a float - where the ultrasonic wave bounces off - both an aluminum-lined unicel sphere and a cork disk also lined with aluminum, both have excellent buoyancy.

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Based on various tests, the convenience of opting for the aluminum-lined cork float was determined; the attributes in its favor were that it protruded less from the surface of the water compared to the sphere that practically its 4 cm in diameter were out of the water, which increased the height offset measured by the ultrasonic sensor, furthermore its curvature leads to less accurate measurements of the echo time of the sonic signal. The ultrasonic sensor-float set of PVC cork-pipe was fixed vertically to the interior of the 19-liter plastic bucket. Taking advantage of the fact that the liquids maintain the same level due to the "property of communicating vessels", that is, the water level will be the same outside that inside the PVC pipe, as long as it has perforations that allow water to be evenly distributed. . These perforations are in the lower side of the PVC pipe.

"Communicating vessels" is the name given to a set of containers communicated by its lower, upper or lateral part and that contain a homogeneous liquid; it is observed that when the liquid is at rest it reaches the same level in all the containers, without influencing the shape and volume of these. When we add a certain amount of additional liquid, it moves to a new equilibrium level, the same in all containers. The same happens when we tilt the glasses; although the position of the vessels changes, the liquid always reaches the same level. This is because the atmospheric pressure and gravity are constant in each vessel, therefore, the hydrostatic pressure at a given depth is always the same, without influencing its geometry or the type of liquid. Blaise Pascal demonstrated in the seventeenth century, the pressure exerted on a mole of a liquid, is transmitted in its entirety and with the same intensity in all directions (Pascal's Principle). "
(Wikipedia enciclopedia libre, s.f.)

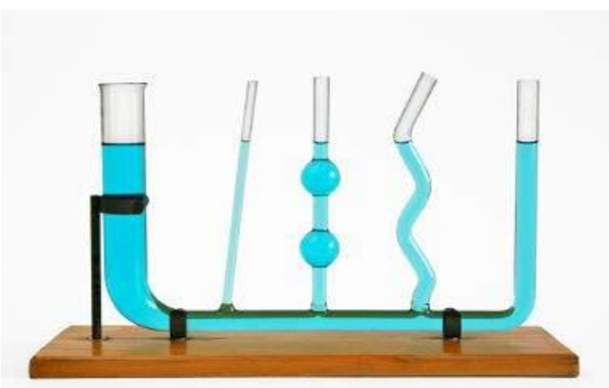

Figure 7 Communicating vessels
Source: www.google.com

The ultrasonic sensor was properly fixed on the top of the PVC tube, keeping a safe distance from the maximum water level of the cuvette, this distance is approximately 15 cm. Electrical cables were added as a means of connection of the ultrasonic sensor with the Arduino Mega card and thus power the first voltage and receive and send the signals to be processed to quantify the proximity distance of the float with respect to the ultrasonic sensor.

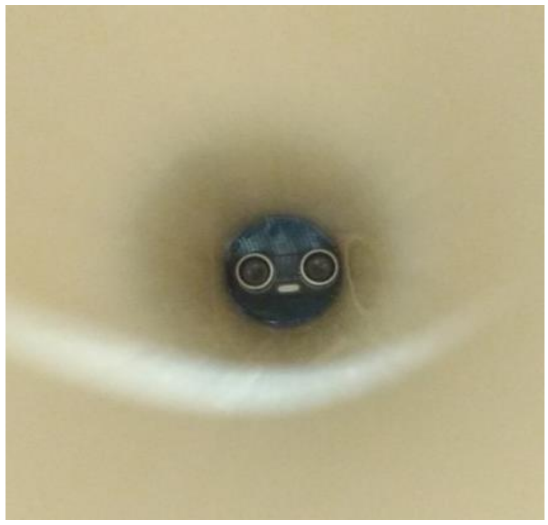

Figure 8 View inside the PVC tube where the ultrasonic sensor was placed
Source: Own Elaboration

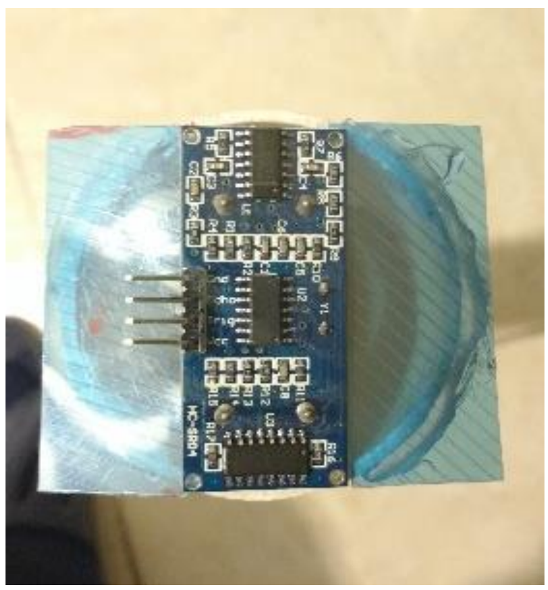

Figure 9 Ultrasonic sensor placed on one end of the PVC pipe
Source: Own Elaboration

Figure 10 PVC tube assembly, ultrasonic sensor with cables and aluminum-lined unicel sphere.
Source: Own Elaboration

Figure 11 Disc type float, aluminum lined cork material placed in the PVC pipe
Source: Own Elaboration

The Arduino Mega card is the core element of control, it energizes and receives the signals from the ultrasonic sensor and with the appropriate program and relevant calculations the float distance is determined, from this and other data such as maximum water level height, radius of the container bucket; You can process and calculate variables to be monitored, such as: height of the fluid level, fluid volume and percentage of filling of the cuvette. These variables are issued as digital information via Bluetooth wireless communication using the HC-05 module, which will establish communication with a Smartphone-type telephone using an application specifically designed for it.

It is worth mentioning that a 16x2 LCD display is also connected to the Arduino Mega to locally visualize the variables of fluid level height and fluid volume. This connection of the LCD involves the electrical energization of the same, the control signals, data signals and contrast control on the screen. The aforementioned parts are for the moment exposed for experimentation, thinking that in a later development they can be contained in a hermetic cabinet for their protection.

Figure 12 Integration of the elements for the water level measurement system contained in the bucket
Source: Own Elaboration

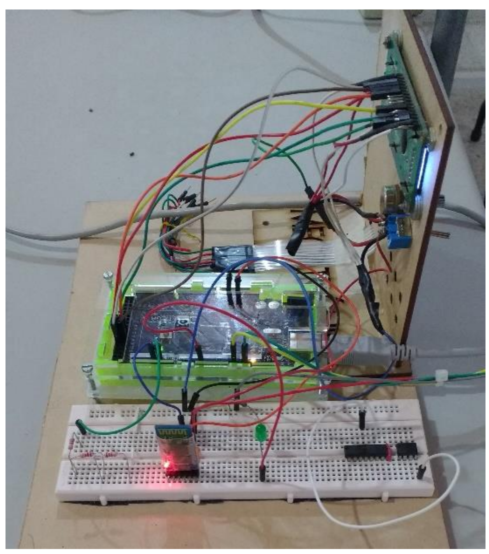

Figure 13 System composed of LCD display, Arduino Mega and Module HC-05
Source: Own Elaboration

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Arduino programming

A conceptual and general description of the program generated in the IDE environment of development, edition and compilation of Arduino is the one described below:

Calling libraries to support the program, specifically the management of the LCD display.

Declaration and types of variables to be used.

A void setup () function, where the required inputs and outputs are configured, the LCD display is initialized and initialization of the serial ports.

A void radar function (), where you have the instructions to use the HC-SR04 ultrasonic sensor, obtain the response time of the sonic echo, calculate the distance of the float placed inside the PVC tube and other calculations to determine height the water level, fluid volume and filling percentage; considering the appropriate adjustments in the equations.

A void monitor () function, where information is displayed on the personal computer on the serial monitor of the Arduino development environment.

A void function displays_LCD (), where you have instructions to display the information on the LCD display.

A void function communicates (), where you have the instructions to establish bidirectional communication with the Bluetooth module HC-05 and display the information on the smartphone, which has an app application edited for this purpose.

A main and cyclic function void loop (), where the previous functions are called for execution as subroutines.

```
float altura_max=25.25; // altura máxima de la columna de agua en cm, equivalente a 15 litros en l
float radio= 14.4; // radio en cm de la cubeta cilindrica
float pi=3.14; //constante matematica
float diametro_esfera= 3.6; // esfera flotador en cm que detecta el sensor ultrasonico
float factor_correcion=14.5;//factor de correcion para altura en cm

char caracter=' ';

void setup() {

void loop()  //programa principal ciclico
{

void comunica ()
{

void radar() //rutina para utilizar el sensor ultrasonico y realizar calculos
```

Figure 14 Part of the program code loaded on the Arduino Mega card
Source: Own Elaboration

Development of the application on the Smartphone

In order to create our app we use the open source software called APP INVENTOR. It is only necessary to be connected to the Internet (Wifi) in order to use the inventor App, create an account in Gmail and have an Android device that uses the same Wifi network. The route to enter and use the software is:

http://ai2.appinventor.mit.edu.

The programs are done intuitively using blocks, which are a kind of "puzzle" pieces. It has no source program written in text.

App Inventor appeared on July 12, 2010, and was opened to the public on December 15, 2010. It was developed between Hal Abelson of MIT and Google engineers Ellen Spertus and Liz Looney, along with David Wolber professor of USFCA and developer of the application.

At the beginning of August 2011, Google announced that it would no longer maintain this application, but that it would make it open source for education.

A week later, the Massachusetts Institute of Technology (MIT), a private higher education institution located in Cambridge, Massachusetts (USA), announced that it would take over the project.
In December 2013, MIT released AI 2, a new version of App Inventor.

In November 2014, the language option comes out, which allows us to see most of the elements in Spanish.

The Inventor App is not a program that has to be downloaded to the computer.

It works in cloud computing (the cloud), the program works by connecting to the Internet and works directly connected to the App Inventor server. It's like a web page and operations are carried out in it; you only need a Gmail account.

Figure 15 Development of the screen for the application of variable monitoring.
Source: Own Elaboration

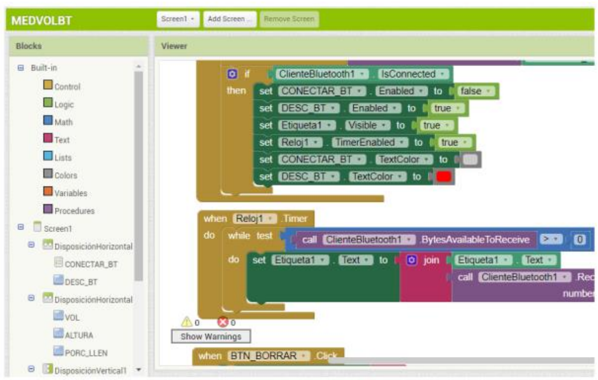


Figure 16 Part of the code that was edited in the programming block editor
Source: Own Elaboration

Figure 17 Information unfolding in app app on phone and LCD display
Source: Own Elaboration

Figure 18 Application app screen on smartphone
Source: Own Elaboration

Formulas used

The echo time of the ultrasonic signal is obtained as a result of the division between two of the time inverted by the sound that travels back and forth from the sensor to the surface of the fluid. The calculation of the average time of the echo (μs), result of the averaged sum of the 50 samples made every 0.5 seconds, is subjected to rounding by the instruction round:

$$tiempo\_eco = round(\frac{tiempo\_eco}{50}) \qquad (2)$$

For the calculation of the distance (m) between the sensor and the fluid surface, considering the speed of sound:

$$distancia = tiempo\_eco * 0.0003432 \qquad (3)$$

The height of the fluid level (cm) contained in the cylindrical bucket is calculated, also taking into account the thickness of the cork disk float:

$$altura = altura_{max} - (distancia * 100 + corcho) \qquad (4)$$

The conversion factor of 1 liter must be taken into account = 1000 cm^3.

We calculate the volume (lts) that displaces the PVC tube as the level of the fluid in the container increases, considering the outside radius and the inside radius to obtain the area of the thickness of the PVC pipe:

$$volumen_{tubo} = (\pi * 2.5^2 - \pi * 2.3^2) * altura/1000 \quad (5)$$

The volume (lts) of the fluid contained in the tank is calculated, taking into account the inner radius of the tank, the height of the liquid, as well as the volume displaced by the PVC pipe and the initial 3 liter tare already contained in the tank bucket:

$$volumen = \frac{\pi * radio^2 * altura}{1000} - volumen\ tubo + tara \quad (6)$$

Finally, the filling percentage is calculated based on the maximum volume of 15 liters to be in the bucket:

$$porcentaje = \frac{volumen * 100}{15} \quad (7)$$

Tests and results

To carry out the tests, a graduated beaker was used to pour one liter of water into the container, and a graduated scale was stuck inside the tank to obtain a reading of the fluid height level (water) mention that we tried to have the correct leveling of both the table where the bucket was placed and other elements, for this the classic bubble level was used.

Measurements with the rule entail the error of parallelism, this when measuring the height of the surface of the water to determine the height of the level, we must also consider the range of variation of +/- 3mm of the ultrasonic sensor HC-SR04, as well as the variability of the propagation of the speed of sound as a function of the temperature of the environment and relative humidity.

All the aforementioned allows us to understand the reason for the variations and inaccuracies of the experimental results.

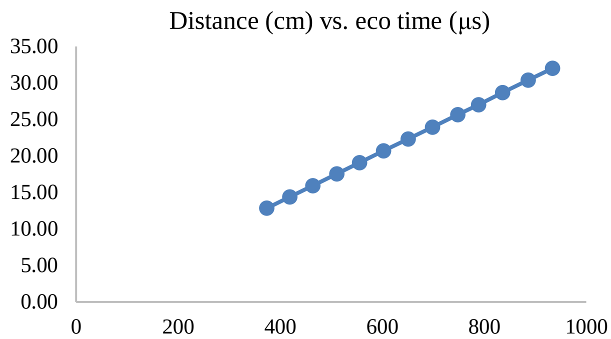
Below, we present a table of the measurements of the publications made, as well as the calculations generated by the system based on the Arduino platform.

Table of experimental measurements

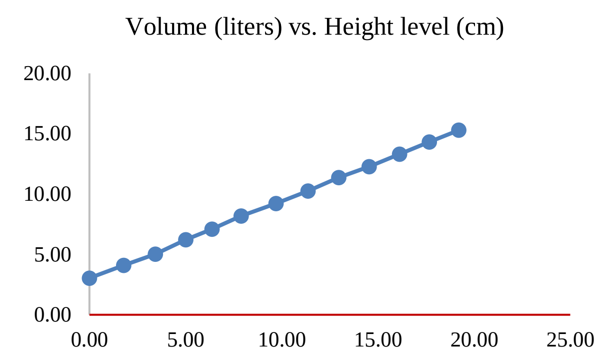
Fluid volume poured into a container with graduated pipette, without tare (liters)	Measured Eco time (microseconds)	Distance to the surface of the fluid quantified with ultrasonic sensor - Arduino (cm)	Fluid level height calculated with Arduino (cm)	Fluid level height measured with graduation (cm)	Absolute height error (calculated - measured) (cm)	Fluid volume calculated with Arduino + tare (liters)	Container filling percentage of 15 liters maximum calculated with Arduino (%)
0	934	32.00	0.00	0.00	0.00	3.04	20.27
1	886	30.40	1.78	1.70	0.08	4.09	27.59
2	836	28.69	3.43	3.60	0.17	5.02	33.58
3	789	27.04	5.01	5.40	0.39	6.22	41.34
4	748	25.67	6.38	7.20	0.82	7.10	47.34
5	699	23.96	7.89	8.80	0.91	8.18	54.51
6	651	22.34	9.71	10.50	0.79	9.23	61.53
7	603	20.69	11.36	12.20	0.84	10.26	68.40
8	556	19.08	12.97	13.80	0.83	11.38	75.28
9	511	17.54	14.55	15.40	0.85	12.28	81.86
10	464	15.92	16.13	16.90	0.77	13.31	88.74
11	419	14.38	17.67	18.50	0.83	14.32	95.47
12	374	12.84	19.21	20.30	1.09	15.29	102.05

Note: tare of 3 liters of fluid (clean water).

Table 1 Experimental Results
Source: Own Elaboration



Graphic 1 of data obtained according to Table 1
Source: Own Elaboration



Graphic 2 of data obtained according to Table 1
Source: Own Elaboration

The results denote that there is a margin of variability between what was calculated and measured as regards mainly the height of the fluid level contained in the cuvette, with an average of 0.7 cm of error. Which we consider is not significant for the height of the level shown and monitored; however, these variations in height do affect the results of the volumes calculated, showing an increase in the volumetric value on average of 0.22 liters above the real value of water poured with the beaker.

In the previous graphs, a linearly acceptable behavior of the different variables measured and calculated is observed.

Figure 19 Container with terminal strip, PVC tube with ultrasonic sensor and graduated beaker
Source: Own Elaboration

Conclusions

Once the present project has been carried out and the results obtained have been evaluated, the following conclusions can be expressed. The system was functional and considering its margin of error, it is acceptable for the experimental purposes of this prototype, the main factors that generate deviations in the accuracy of the results are that the first float is spherical and therefore the rebound of the ultrasonic signals probably not entirely uniform, so we chose the float cylindrical cork disk; the float has oscillations of its height when the fluid is added or removed quickly, so that we must wait for the surface of the water to settle down a little; there are errors inherent in the measurement, such as the volume of fluid that displaces the same PVC tube as more water is added to the container, the small variability in the time measurement of the echo signal of the ultrasonic sensor, the small irregularities of the container of water, the dimensional measurement errors of the container and its height.

The monitoring of the variables height of the fluid level, fluid volume and percentage of filling by the Smartphone has a limited scope due to the maximum distance inherent to communication via Bluetooth (10 m maximum), but meets the expectations of having a remote process monitoring safely.

If another type of fluid level height sensor is used with greater reliability and accuracy, it can be connected to the Arduino Mega - Bluetooth card system and achieve the desired remote monitoring with the smartphone. But it should be mentioned that commercial ultrasonic level sensors for industrial use are around the price of over $ 500, and in this developed system its price was around $ 50, a tenth of the cost.

The system was developed on a small scale of measurement, no more than 30 cm high fluid level and a capacity of 15 liters; but it can be extrapolated to larger measurements that do not exceed 4 m (limitations of the range of the ultrasonic sensor used), with the adjustments in regard to the height sensor of the fluid level.

Finally, considering the cost-benefit relationship, we can conclude that the present prototype fully met the objective.

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