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Control of a drinking water quality monitoring and pumping system

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Abstract*– Climate change, energy saving and access to water are issues of great interest to society. Now, thanks to the advent of the Internet of Things and microcontrollers, numerous potential applications have opened up. This paper proposes the design of a pump control system and monitoring of drinking water quality. This system is usually applied in the industrial area, however, here it seeks to incorporate it in rural and urban areas, for use in buildings or homes. This manuscript describes the automation of the process of filling water tanks. Unlike other similar systems, this one can automatically fill the tank and monitor the water quality in real time to anticipate its respective maintenance. The ESP32 was used as the main controller, which acquires the values measured by each of the sensors. Sensor data can be viewed from a mobile app via a Bluetooth connection. Finally, the implementation of this automated system is described through a prototype, where the data is shown in real time.

Keywords—Automation, ESP32, sensors, home automation, water quality

I. Introduction

Currently, automation is extensively applied in industrial tank level control to optimize time, reduce personnel costs, and minimize the need for additional instruments [1]–[3]. However, in rural and urban sectors, the majority of these systems still rely on manual operation. This dependence on human intervention for pump activation and deactivation often leads to incorrect procedures, thereby diminishing the motor's lifespan.[4]. Maintaining the water pump in optimal condition is crucial, as improper usage entails not only additional repair or replacement costs but also interruptions in water supply and potential negative impacts on water quality, particularly in terms of potable water. In addition, when talking about drinking water, it is important to keep it in proper conditions for human consumption. Additionally, it is vital to preserve water in appropriate conditions for human consumption. Therefore, assessing water quality is immensely helpful for undertaking the necessary reservoir maintenance [5], [6]. Otherwise, it is possible to be exposed to diseases related to water contamination. Several studies have showed a list of these diseases, some of which can be fatal, mainly affecting children [7]–[11].

In this context, it is imperative to research and develop more efficient and automated solutions for tank level control in rural and urban environments, aiming to minimize human errors and ensure optimal lifespan of the water motor. Additionally, implementing continuous water quality monitoring mechanisms is crucial to properly maintain and preserve water tanks. Accurate knowledge of water quality levels will enable proactive measures and interventions to prevent contamination of drinking water. By safeguarding the health and well-being of communities, particularly children who are more vulnerable to waterborne diseases, a consistent supply of quality drinking water is ensured, promoting sustainability and well-being in both rural and urban sectors.

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Over the last few years, different solutions have been proposed to automate the pumping system and monitor water quality [12]–[14]. However, some of these solutions are very expensive and do not convince to use them.

In research that measures water quality, first, the physicochemical properties of the water are measured to verify that they are within the ranges established by the WHO (World Health Organization) and, thus, to determine its quality [15]–[18]. For this purpose, different sensors are used to measure these parameters. These are connected to a microcontroller to collect the information and then be displayed on a screen [19]–[25]. In [21], [26] waterproof temperature, pH and turbidity sensors were used to determine water contamination. On the side of the research that seek to control the switching on and off of the water pump, waterproof ultrasonic sensors are used as in [27] that determine the water level in the tank. Depending on how full it is, the signal is sent to the pump through a relay to turn on or off.

A microcontroller capable of receiving and sending the information is used to process the information collected by the sensors. In many researches, Atmega328 has been used, as is the case of and [26]–[30]. Most of them have used an Arduino board that carries the mentioned microcontroller [30]–[33]. In [31], [34]–[36], a Raspberry board was used to communicate with a database.

Once the information obtained by the controller is ready to be sent, it is necessary to have a communication path. In the case of [37], a cloud database is used because the sensors are located far away from where they are going to be monitored. Therefore, it requires a Wi-Fi module to achieve communication between the microcontroller and the central controller. Something similar happens in [21], [27], [30], [38] where modules such as XBee or Bluetooth are used for sending and acquiring data. Not far away, in [26] a SIM900 module is used to send SMS messages and display the processed information from a cell phone.

To monitor the required variables, a visualization system is required. In the case of [26], [30], [39], [40] a mobile application was used, which was developed on the MIT App Inventor 2 platform. However, in [34] a Human Machine Interface (HMI) installed on a computer was used. A very effective solution if the monitoring room is close to the place where the parameters are measured.

All research consulted proved to be good solutions to determine water quality and control the pumping system. However, in [41] it is recommended to perform a study supervised by experts to compare the values obtained to ensure optimal and reliable results. In the data measurement, it is appreciated that the system can process the information with a 100% reception/transmission rate since the variation of the data varies over long periods of time as shown in [27]. In most of the investigations, three to more different sensors were used to achieve water quality measurement, e.g., temperature, oxygen, conductivity, turbidity, and others [21], [42], [43]. However, in [44] only the pH sensor was needed to reach the same result, since it deals with wastewater.

With this, it is already considered that the different electronic devices proved to be accurate and very useful. For this project, a pH sensor and a turbidity sensor will be used to determine the quality of the drinking water, avoiding the use of other sensors to reduce costs. The exclusive use of those sensors in this project to assess the quality of drinking water does not compromise the system's accuracy. Despite previous research on water contamination in general, as referenced in studies [21] and [26], the selection of these two sensors is sufficient for our specific purposes. These sensors provide reliable and continuous measurements of water pH and turbidity, enabling us to accurately evaluate the quality of drinking water. Furthermore, a waterproof ultrasonic sensor will be employed to detect the level of potable water in the reservoir. It is worth noting that the control system utilized in this research will be of the ON/OFF type, also known as a binary controller. This type of controller operates based on the water level variable, determining whether the pump should be turned on or off depending on whether the water level reaches a specific threshold. The selection of the ESP32 SoC was driven by its low cost and power consumption. In contrast to previous studies that utilized the Arduino Nano, the ESP32 features Bluetooth v4.2, including Bluetooth Low Energy (BLE) technology. This makes it ideal for connecting with Android and iOS devices. Furthermore, the ESP32 can be programmed using the Arduino IDE, simplifying the programming process, and facilitating its integration into the ON/OFF control system. This microcontroller will be able to receive data from the sensors, process them and send that information to the mobile application through the Bluetooth module. This application will be developed in Google's Flutter SDK, which is open source and multiplatform. This means that the application will be able to run on Android, iOS, and Web. That said, the aim of this research project is to design a system that allows to census the variables that exist in a drinking water tank such as water level, pH level and turbidity.

II. METHODOLOGY

To better understand the complete system, Fig. 1 shows the different blocks that compose it. First, the perception system where the sensors are located. Then, the control system that collects the acquired data. Then, the on/off signal is sent to the motor and, through the data acquisition and sending block, it is sent to the display system to observe the variables.

A. Perception system

The perception system oversees collecting the data and information of the different variables. The first sensor to be used is the JSN-SR04T ultrasonic sensor, which is waterproof exclusively for use in humid places; however, for demonstration purposes the HC-SR04 will be used, which has a measurement range of 2 to 500 centimeters, a detection angle of 15 to 20 degrees and works at 5V. The second is the ST100 turbidity sensor, which is essential for quality assurance and control of the materials found in the liquid, which will be used to measure the particles suspended in the water using the scattered light measurement principle, it has a response time of less than 500ms and works at 5V. Finally, the pH sensor 4502C, which has an electrode and its control module, must be calibrated by measuring liquids with known pH. If this is the case, the coils of the module are adjusted until a more accurate value is obtained. Finally, the values collected by the different sensors are sent to the ESP32.

B. Control system

The control system will be responsible for receiving, processing, and sending the data obtained from the sensors. The control unit is the ESP32. It will send a trigger signal when it detects that the water level has dropped below the set height.

C. Drive system

The drive system will consist of the water pump (motor), which is responsible for transforming the energy to move fluids from one place to another. It is used to increase the water pressure by adding energy to the hydraulic system to move the fluid from a low-pressure zone to a high-pressure zone. The water pump will be driven through a relay by the microcontroller since it oversees sending the signal to turn the motor on and off.

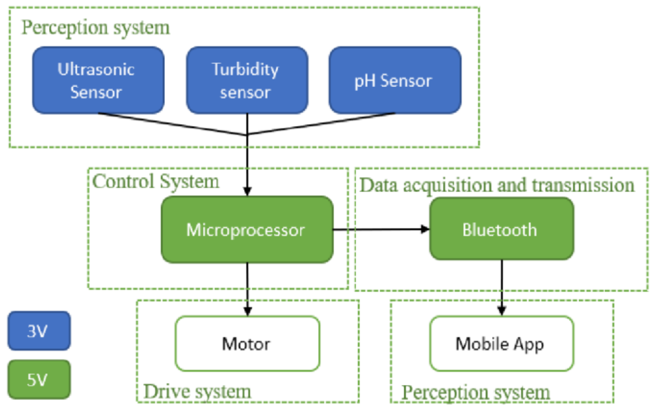

Fig. 1. Block diagram of the automated system.

D. Acquisition and transmission of data

In the data acquisition and sending stage is the integrated Bluetooth of the ESP32, which will have the function of establishing wireless communication with the mobile device.

E. Display system

An interface will be created to visualize the status of the water tank in real time on a smartphone or mobile device. This will be done using Flutter, which will allow the creation of an application to receive system data such as water level, pH and turbidity. It will be linked to the ESP32 through its Bluetooth module allowing connectivity when the tank status needs to be viewed.

F. Installation diagram

This system can be better appreciated with an installation diagram as shown in Fig. 2. Here you can see the different sensors to be used and the respective connections for proper operation. As well as the tank measurements to calculate the appropriate limit values.

As can be seen, we will be working with a tank of 1100 liters, which means that its height is 140 cm, according to the standard in the current market. Knowing this, it must be considered which are the limits for the pump to turn on or off. For this, the upper limit will be 15 cm and the lower limit will be 135 cm: acceptable ranges for the chosen ultrasonic sensor. These values have been chosen to prevent the water level from overflowing and to avoid being completely empty. It should be noted that the cistern limits are only used to avoid turning on the pump when no water is available.

G. Contaminating factors of a tank

Contamination of drinking water for human consumption in tanks and cisterns is caused mainly by inadequate protection of the physical part of the water storage tanks, as well as inadequate cleaning and disinfection of these reservoirs periodically. The main factors that contaminate a water tank were: Inadequate physical protection, accumulation of sediments (soil), organic matter and garbage.

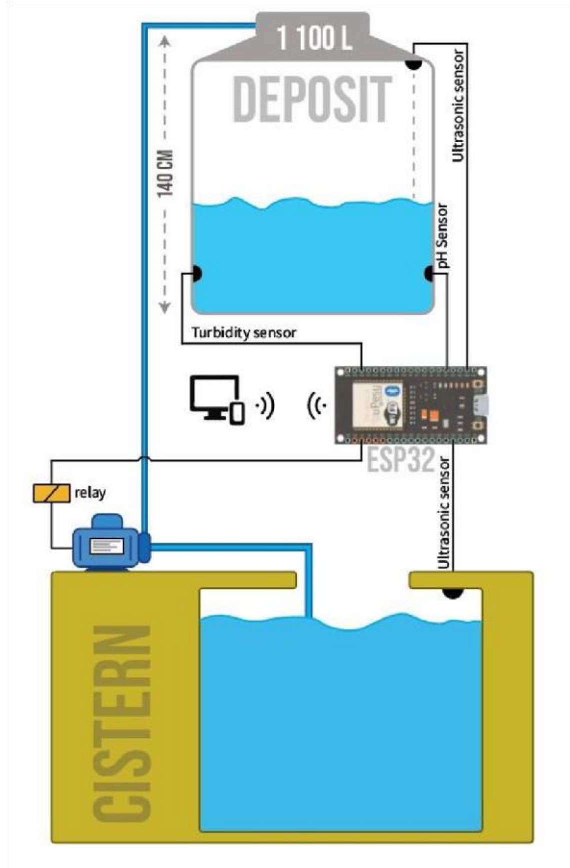

Fig. 2. Installation diagram of the system.

H. Filling of a water tank by manual ignition

A water tank is always located at the top of a building or base, as pressure is needed for the water to be distributed by gravity. Only in the case that the tank is very high, or the water pressure is very low, a motor is used so that the water can rise. In many cases a cistern can be used that receives the water from the mains and from there the water tank is filled through the motor. The operation of filling a tank begins in the main water supply network that fills the cistern. This is filled through an endless filling valve, from which a water tank float is connected. The main use of this float is to allow water to pass through when it is down and to stop when it is at its peak. Once the cistern is full, the water pump is turned on to fill the elevated tank, which is filled in the same way as the cistern. On the other hand, it is also common to see the filling of a tank without a cistern, which does not require a pump because there is already the necessary pressure for the water to rise.

I. Considerations for determining water quality

According to WHO, some properties of drinking water should be certain of the degree of water quality. Among them, the main ones are the following: microbiological properties, where the presence of microorganisms can be noted; physicochemical properties, where parameters such as pH, turbidity, absorbance, and other elements are considered; and finally, aesthetic properties, where there are parameters visible to the human eye or sensory such as total dissolved solids, temperature, taste, color, odor, and salinity of the water.

As this design deals with drinking water and focuses on the urban sector, it is sufficient to consider only the physicochemical properties to determine water quality. Only the turbidity of the water and pH will be taken into consideration to ensure that the water is fit for human consumption. In this way, you will have what you need to know when the reservoir will be serviced.

The acceptable pH range for drinking water is between 6.5 to 8.5, with extreme values can cause irritation to mucous membranes, internal organs, and ulceration processes.

J. Hardware

For the choice of hardware, the ESP32 SoC was considered for its small size, low price, and power consumption, compared to other alternatives. It has Bluetooth v4.2 technology for connectivity with Android and iOS devices. In addition, it has the necessary inputs and outputs for the development of this system. It is an alternative that fits very well with the instruments mentioned above.

K. Software

For the programming of the ESP32 we chose to use the Arduino IDE because it allows it through a library. It can connect to the chip and load the program. It also has the advantage of offering a console that shows where failures have occurred and thus repair them. [3]

On the mobile application side, Google's Flutter SDK has been used, which is free to use and easy to program. Through third party libraries it can be programmed to be able to connect to the ESP32 Bluetooth.

L. Flowchart

To program the ESP32, the diagram in Fig. 3 will be used, which indicates the main steps that must be carried out for correct operation.

As can be seen, after defining the inputs and outputs, the Bluetooth parameters must be correctly configured so that it can be recognized by other devices and be able to send data. After obtaining the values of each sensor, we proceed to calculate its parameters, i.e., convert those values to the scale of each sensor. For example, the pH sensor gives a voltage and that must be converted to the scale from 0 to 14. Then, they are converted into a list of characters for serial communication and sent to the mobile application. Then, as the system must operate automatically, it enters an endless loop where it will ask if the water level is at the upper limit to turn the motor off, otherwise it will ask if it is at the lower limit to turn it on. If it is not at either, it will repeat the loop until it is at one of them.

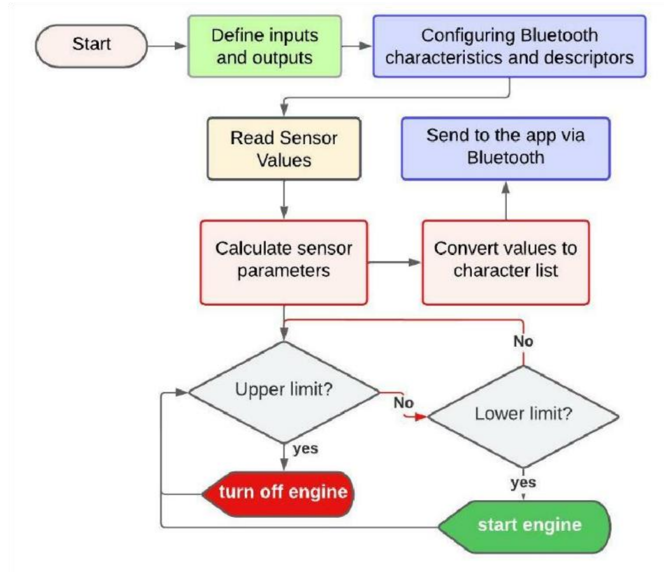

Fig. 3. ESP32 programming flowchart.

M. Bluetooth configuration

As mentioned above, the built-in Bluetooth is a Low Energy technology, so its parameters must be correctly configured to send and receive information. As shown in Fig. 4, first a server is created and, within it, a service. Then, a feature is created for each sensor to be used. Then, to obtain the values of each sensor, a descriptor must be created.

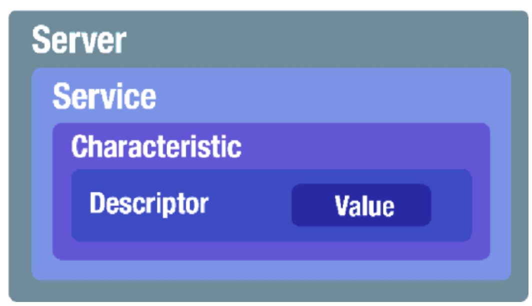

Fig. 4. BLE configuration of the ESP32.

Once everything is configured, it is possible to communicate with any device connected to the ESP32. What is done in the application programming is to read the descriptor value of each feature and display it in real time.

N. Demonstration installation diagram

As shown in the installation diagram in Fig. 2, the system is intended to be implemented in a real environment with large tanks and a water motor. However, for demonstration purposes a smaller system has been designed using a 5V mini water pump and tanks of a smaller size as shown in Fig. 5. To ensure proper operation of the sensors and to demonstrate that the measured values can be viewed in real time from the mobile application.

As the dimensions of the tanks are smaller, the upper and lower limits should be smaller. Considering that the ultrasonic sensor has a measurement range of 3 to 500 cm, an upper limit of 5 cm and a lower limit of 23 cm will be used to avoid problems with short distance readings.

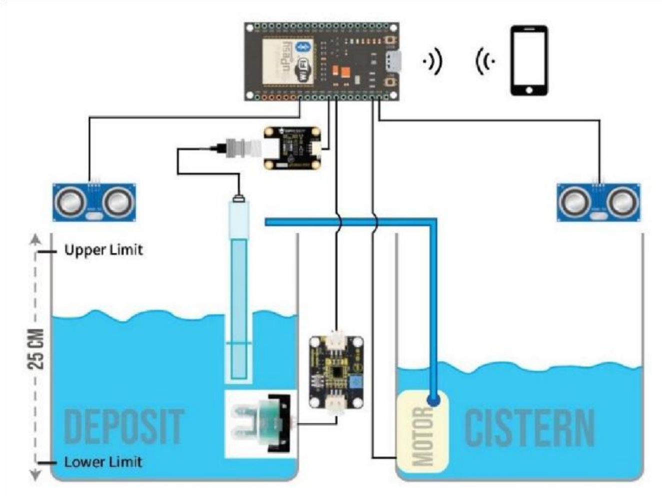

Fig. 5. Demonstration installation diagram.

Also shown is the connection of the pH and turbidity sensors connected to their respective interfaces that will allow the appropriate values to be sent to the ESP32.

To operate the 5V motor it is not possible to feed it with the pins of the board, due to its low voltage levels. Therefore, it is necessary to use a connection like the one shown in Fig. 6, which only requires a signal to be sent to the transistor to provide the necessary voltage to the motor.

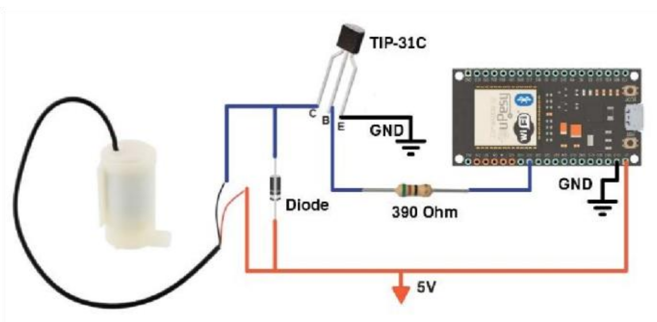

Fig. 6. Motor connection diagram.

In this way, the motor on/off can be controlled by sending a signal through one of the ESP32 pins to the transistor.

III. Results

The mobile application installed in the device can connect via Bluetooth with the ESP32 using BLE technology and display the distance in real time. As shown in Fig. 7, a ruler was used to measure the real distance to an object and on the right side the mobile application is shown indicating the distance measured with the ultrasonic sensor.

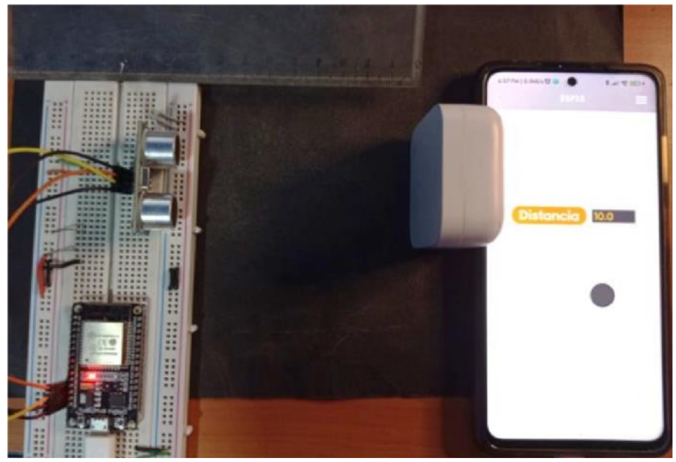

Fig. 7. Ultrasonic sensor functional test

With this test it can now be implemented in the tank to measure the water level and send the signal to the motor to turn it on or off.

For this system, two ultrasonic sensors were used, one for the tank and one for the cistern. The tank sensor has the task of turning the pump on or off according to the upper and lower limits. While the cistern sensor calculates the water level to ensure that there is water that can be pumped. This avoids the risk of turning on the pump when there is no water for reasons beyond the control of the system. The value of this level is not shown in the application, instead, it indicates whether there is water present. The screenshot of the completed mobile application can be seen in Fig. 11.

When testing the ultrasound sensors, there were no complications with the values read by the ESP32. However, the same did not happen with the turbidity and pH sensors, because they deliver analog values and, due to a factory failure, the chip is not able to read these values correctly. Therefore, for this opportunity, we will opt for the support of an Arduino UNO board to take these values and send them to the ESP32 by serial communication. The final assembly of the demonstration prototype can be better appreciated in Fig. 10.

Fig. 8. Calibration of pH sensor

Once the values can be correctly obtained from the pH and turbidity sensors, we proceed to calibrate them; according to the indications shown in [44]. First, for the pH4502C sensor, the control module is supplied with a voltage of 5V and the electrode is introduced in the pH 4.00 solution to make the first calibration; it is waited approximately 1 minute to obtain an accurate value. This is repeated with another pH 6.86 solution. If necessary, the final value is increased or decreased in the code. The calibration process is shown in Fig. 8.

Once the pH values match those in the sachet of each liquid solution, it will be correctly calibrated. The turbidity sensor is then calibrated in a similar manner. In this case, liquids with different degrees of turbidity were used as shown in Fig. 9.

Fig. 9. Calibration of the turbidity sensor with different samples

In this case, the sensor was programmed to give a value from 0 to 5V. Unlike [44] which uses a scale from 0 to 3000 NTU. We chose to use only the voltage because we will not need so many intermediate values for the value displayed in the application; we simply want to know if the water is opaque or clean. For this, we define a reference voltage of 3.5V and then it will be shown as opaque water when the voltage is below and clean when it is above.

Once we have the sensors calibrated, we make the connections as shown in Fig. 5 and compile the program in the ESP32.

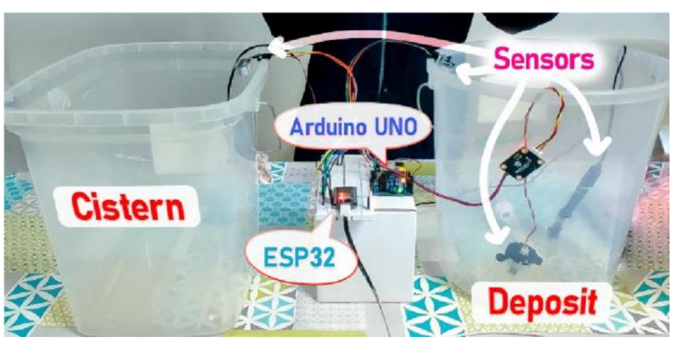

Fig. 10. Demonstrative model of the system.

Then, the smartphone with the installed app is used to observe the water level and the pH and turbidity levels. Additionally, the filling and discharge rate of the tank was added. This data was calculated by determining the water level at one time and then subtracting it with the previous time. Since the response time of the system is exactly one second, the subtraction gives the velocity in centimeters per second. To convert this to liters per second, multiply by the liters per centimeter in the tank. This factor is calculated by dividing the total capacity by one centimeter. Finally, we would have the speed in liters per second of the discharge and filling of the tank.

With the prototype implemented, we proceed to test both the sensor measurements and the automatic switching on and off. As shown in Fig. 11, the mobile application shows the sensor parameters calculated by the ESP32, such as tank level, presence of water in the tank, pH, and turbidity. It also shows when the motor is on or off and the filling or discharge speed.

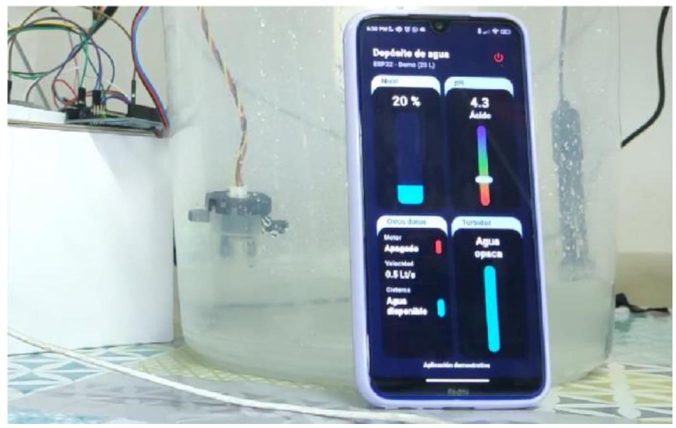

Fig. 11. Mobile application showing values measured by sensors.

It should be noted that the response time of this system is exactly 1 second; the ESP32 is programmed to update in that time. It was done that way to facilitate the calculations and avoid communication problems. In addition, it is an adequate time to display the variables in real time.

The implementation of control and monitoring systems in potable water tanks entails associated costs, such as the acquisition of sensors and system maintenance. High-precision level sensors have a price range between $20 and $30, while water quality sensors range from $40 to $50. Additionally, the costs of periodic calibration should be considered, estimated at approximately $360 per year. Despite these costs, the implementation of these systems can yield long-term savings by reducing water losses and preventing issues with water quality. In summary, the economic benefits support the feasibility and profitability of these systems in potable water tanks.

Finally, in comparison to conventional procedures used in the industry, this control and monitoring system offers distinct advantages in terms of efficiency and cost-effectiveness. Traditional industry practices often rely on manual interventions and constant supervision, whereas the proposed system provides a real-time automated solution. In terms of efficiency, the proposed system reduces dependence on human intervention, minimizing the risk of errors in pump activation and deactivation. Additionally, the capability to monitor water quality in real-time through pH and turbidity sensors enables early detection of potential contamination issues, facilitating swift response and ensuring the preservation of potable water quality.

IV. Conclusions

This paper presents the development and implementation of an automated system for turning on and off a water pump and census of water quality, which aims to verify that the measured variables are displayed in the mobile application in real time. For this purpose, it has been demonstrated with an example using a mini water motor, an ultrasonic sensor, a pH sensor, and a turbidity sensor.

With this it can be concluded that the system is able to detect the level of the water and then turn on or off the water pump when it is at a certain level. At the same time, the pH and turbidity levels that determine the water quality are shown.

With respect to the operation of the sensors, it should be noted that it was necessary to perform an adequate calibration to ensure that the values displayed are accurate. In this way, it was possible to observe that these values are within what is allowed by the WHO for drinking water.

For this project, pH and turbidity were used to determine water quality, avoiding the use of other sensors that increase the total cost. However, it is recommended to use the temperature sensor to have more control over the quality grade.

Since the feasibility of this project was demonstrated with a prototype using low-cost sensors, some drawbacks were encountered at the time of testing. The main problem is the humidity that exists due to water; the turbidity sensor showed erroneous values when water fell inside it and the ultrasonic sensor showed very large or small values for short periods of time. The latter could be corrected so that these changes are not so continuous. However, this is a problem that can be avoided by using waterproof sensors.

On the other hand, with respect to the filling rate, it was kept constant at 50 milliliters per second for a 23-liter tank with a height of 25 cm. For this speed the time to fill the entire tank was approximately 8 min. It is a little slow in this case, since a small 5V pump was used; to improve this, a higher voltage pump could have been used.

Acknowledgment

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