UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Visión Electrónica

https://revistas.udistrital.edu.co/index.php/visele

VISIÓN ELECTRÓNICA

A CASE-STUDY VISION

Implementation of a Water Conductivity Measuring System With Real Time Data Transmission

Implementación de un Sistema de Medición de la Conductividad del Agua

Luis Alfredo Rodríguez Umaña [1], *Santiago Leyva Gaspar* [2], *José Luis Parra Curtidor* [3]

INFORMACIÓN DEL ARTÍCULO

Historia del artículo:
Enviado: 29/08/2022
Recibido: 12/09/2022
Aceptado: 21/12/2022

Keywords:
Bluetooth
Conductivity
Data
Data transmission
Monitoring
Sensors
Temperature
Water

Palabras clave:
Bluetooth
Conductividad
Datos
Transmisión de datos
Monitoreo
Sensores
Temperatura
Agua

ABSTRACT

This document shows the implementation of a water conductivity measurement system with the special attribute of data transmission in real time through Wi-Fi and Bluetooth devices. For the development of the proposed work, an evolutionary methodology was used, which is developed phase by phase, with the possibility of returning to a previous phase to make the pertinent adjustments. Within the development, the KEYESTUDIO sonda measurement sensor TDS V1 sensor module with XH2.54-3 was used, which connects to the ESP8266 data acquisition card together with the DS18B20 temperature sensor, being the IoT platform and a LabVIEW® interface monitoring panels for transmitted data of electrical conductivity and temperature of the chosen environment. It is important to mention that the implemented system provides effective monitoring of water conductivity from a remote location, yielding reliable values, without user intervention in the chosen environment.

RESUMEN

El presente documento muestra la implementación de un sistema de medición de la conductividad del agua con el atributo especial de transmisión de datos en tiempo real por medio de dispositivos wifi y bluetooth. Para el desarrollo del trabajo propuesto se hizo uso de una metodología de tipo evolutivo, la cual se va desarrollando fase por fase, con la posibilidad de regresar a una fase anterior para realizar los ajustes pertinentes. Dentro del desarrollo se hizo uso del sensor KEYESTUDIO sonda de medición TDS V1 módulo de sensor con XH2.54-3, el cual se conecta a la tarjeta de adquisición de datos ESP8266 junto con el sensor de temperatura DS18B20, siendo la plataforma IoT y una interfaz de LabVIEW®

1 Electronic Engineer. Specialist in Automation and Industrial Informatics. Master in Information Technology Management. Assistant Professor, School of Engineering, Faculty of Basic Sciences and Engineering, Universidad de los Llanos. E-mail: lrodriguez@unillanos.edu.co

2 Electronic Engineer, Universidad de los Llanos, Colombia. Specialist in Industrial Instrumentation and Control, Universidad de los Llanos, Colombia E-mail: Santiago.leyva@unillanos.edu.co

3 Electronic Engineer, Universidad de los Llanos, Colombia. Specialist in Instrumentation and Industrial Control, Universidad de los Llanos, Colombia E-mail: jose.parra.curtidor@unillanos.edu.co

Citar este artículo como: L. A. Rodríguez Umaña, S. Leyva Gaspar, J. L. Parra Curtidor, "Implementation of a Water Conductivity Measuring System With Real Time Data Transmission", Visión electrónica, vol. 17, no. 1, pp. 140-151, january-june 2023, https://doi. org/10.14483/22484728.21193

los paneles de monitoreo para los datos transmitidos de conductividad eléctrica y temperatura del entorno escogido. Es importante mencionar que el sistema implementado brinda monitoreo efectivo desde un lugar remoto sobre conductividad del agua, arrojando valores fiables, sin intervención del usuario en el entorno escogido.

1. Introduction

Water, as is well known, is an important natural element for sustaining life; it is used for human consumption as well as in agricultural and industrial processes where its quality is essential. Water purity is a problem that affects production processes. [1] Therefore, the monitoring of its quality and standards is crucial [2]. Certainly, there are many commercially available devices that measure the conductivity of water samples taken from tanks or reservoirs to be used in industrial production processes, which show the importance of water purity. As any purity parameter, it has a unit of measurement, conductivity has several ways to be measured, conductivity is commonly measured in TDS or also called PPM (particles per million) which are the dissolved particles in water and EC (electro conductivity) which determines the ability of water to conduct electricity.[3],[4].

Nowadays, there are portable EC meters that can measure samples in an instant, however, the TDS analysis, which involves analyzing the EC of water, is a more costly and time consuming process. Along with this, it should be noted that the temperature of water correlates with its conductivity because ions move faster between molecules at higher temperatures, so temperature measurement is also taken into account for TDS.[5],[4].

Any aspect related to a variable such as conductivity or EC has to be constantly monitored because it can have repercussions in the taking of action for an industrial production process as in many other scenarios.[6]. Specifically mentioning commercial and industrial fields, the values coming from different sensors determine the process quality so it is essential to have a constant update nowadays due to the implementation of internet of things [7]. For example, the monitoring of vital signs systems in modern hospitals, which transmit data obtained by networks and databases to have real-time status of their patients, this lightens the work of nurses and with a possibility of diagnosis only having the information from a database in real time; this same applies in industry where water is treated for production processes or study [8], [9].

For this project, a low-cost wireless water conductivity measurement device was implemented, unlike what is currently offered commercially for high prices. This allows to monitor two variables in the water without constant intervention as seen today, this a way to automate the water sampling, this allows to analyze this parameter that helps to define the water quality.

Of great importance is the implementation of electrical conductivity measurement systems for the monitoring of various water bodies as can be seen in the work done in [10] where a sensor similar to the present project was used to measure the conductivity of surface water together with other sensors to evaluate the quality from different variables, having an efficient monitoring. This shows the convenience of having a low-cost system implemented for continuous monitoring.

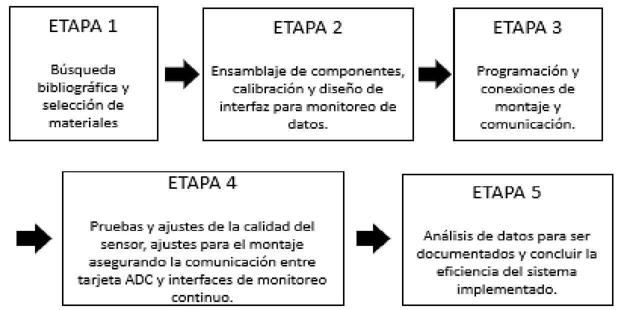
Along with this, it should be noted that the parameters must be studied to model a correct and accurate standard for such an important variable as water. [11]. Defining certain important parameters for the correct analysis of water quality and defining steps for monitoring, methods of analysis, allows to take into account that high conductivity levels in water bring consequences in the field of agriculture, leaving in great importance that the monitoring of individual aspects of water is important for its quality. [12].

The agriculture industry has many standards that need to be met to have good quality products, this is why more devices are needed that can be more accessible to agro-producers users where they have a constant monitoring of influential factors in their processes and in making corrective decisions [12], having a guide for all the above mentioned is useless without sensors to accurately measure the factors that influence one of the most essential natural elements of life [11].

2. Materials and methods

Next, to carry out the implementation of the water conductivity measurement system with real-time data transmission, it is divided into stages to analyze and design the isolated assembly of the fixed monitoring system, and then test the efficiency of the two methods of sending data via Wi-Fi and Bluetooth. The stages are divided as shown in Figure 1.

Figure 1. Stages of the methodology used



Source: Own.

2.1. Component selection and documentation on details of water conductivity characteristics

This stage is governed primarily by the measurement of water conductivity which is affected by the temperature measurement, both sensors have direct exposure to water by the edge of the floating body to take data constantly taking the data to the card located on the board created with the ADC ESP8266 module which has an integrated wifi module and an external HC-06 bluetooth module to transmit

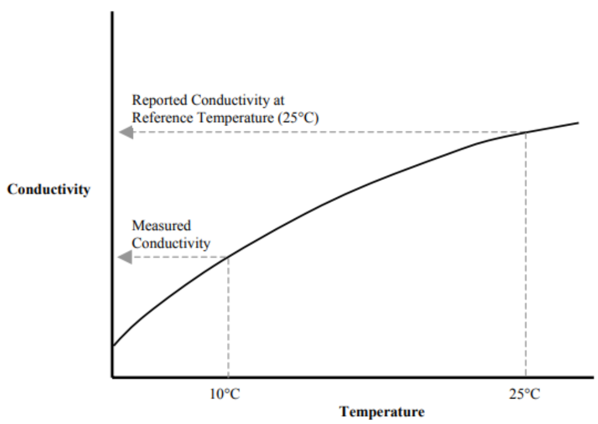
Table 1. Component characteristics.

Component	Role	Features
ESP8266 microcontroller	Reception and sending of TDS and Temperature values.	*Processor: ESP8266 @ 80MHz (3.3V) (ESP-12E)* *WiFi 802.11 b/g/n* *Integrated 3.3V regulator (500mA)* *USB-Serial Converter*
KEYESTUDIO TDS measuring probe V1 sensor module with XH2.54-3	TDS measurement and signal conversion transducer.	*Input voltage: DC 3.3 ~ 5.5 V.* *Operating current: 3 ~ 6 mA.* *TDS measuring range:* *0 ~ 1000 ppm.* *TDS measurement accuracy: ± 10% F.S. (77.0 °F).*
Sensor DS18B20	Temperature measurement.	*Temperature range: -55 to 125°C.* *Accuracy: ±0.5°C (from -10°C to +85°C)* *Capture time less than 750ms*
HC-06 Module	Sending data to LabVIEW® interface	*Operating frequency: 2.4 GHz ISM band* *Distance up to 10 meters*
Power Bank cat ct-18 caterpillar.	Power supplement to ESP8266 card and HC-06 module	*Amperage: 20,000 mAh* *Output voltage: 5 V* *Estimated maximum duration: 18 hours nominal consumption.*

the data. The ADC board is powered with a portable 5V battery forming the whole isolated physical assembly, the characteristics to be taken into account can be seen in Table 1.

Relationship between water conductivity and temperature is not linear; a reference measurement is taken at 25°C. [13]. The coefficient of variation depends on the water solution, the range of variation is established from ~ 2.0 to 5.5 at 25°C [14] for common solutions, the behavior of the coefficient can be evidenced as shown in Figure 2.

Figure 2. Temperature compensation.

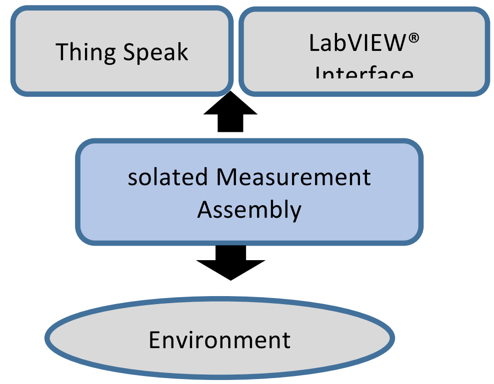


Source: Own.

2.2. Programming design and interface selection for data monitoring

The ThingSpeak.com website was chosen to visualize the data transmitted from the ESP8266 card through its Wifi module due to the flexibility it has to collect, analyze and act on the data. For the LabVIEW® interface, the HC-06 module was used, having these two interfaces, it establishes a possibility of monitoring at a level close to Bluetooth distance as far away from the IOT field. The design was proposed as shown in Figure 3:

Figure 3. Temperature compensation.



Source: Own.

2.3 Programming, assembly and communication connections

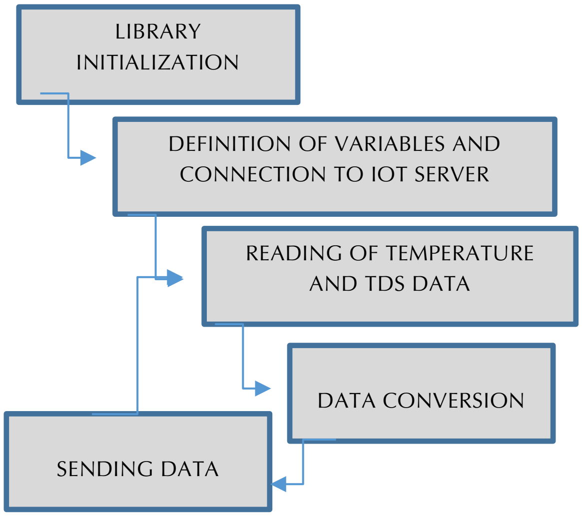
In the programming first we start by defining the variables which are TDS and Temperature. TDS MEASUREMENT: The signal coming from the water conductivity measurement sensor is a 0 to 3.3V signal which has the probe connected by two pins, this signal is processed by the module to be sent to the analog pin which quantifies the signal from 0 to 1024 bits. For the reading is made use of the analog reading of the ARDUINO programming interface.

TEMPERATURE MEASUREMENT: For the temperature reading, the OneWire library was used to make a reading through the digital pin D0. A resistance of 4.7k is used for the configuration given by the library mentioned above, completing the optimal conditioning for data acquisition by means of the DS18B20 sensor.

2.4 Programming Stages

The code starts including the necessary libraries to perform the temperature data acquisition by OneWire and DallasTemperature, the ESP8266Wifi library is included, which allows activating the integrated Wifi antenna together with the parameters for the network and the respective key for the server. Having validated the network and declared the variables in which the data of the variables will be updated, the data acquisition will be performed.

Figure 4. Programming flow blocks.



Source: Own.

In the sensors.request Temperatures() call temperature, activating the algorithm that collects the data obtained by the digital port voltage from 0 to 3.3V to convert temperature values.

The water conductivity measurement uses the signal coming from the analog input pin, this value is obtained by means of the analogRead() function. First the EC (electrical conductivity) value is taken along with the calculated temperature coefficient to obtain, this can be evidenced in equation 1 which consists of the conversion of voltage to EC values:

$$EC = \frac{analogRead(A0) * \frac{voltage\_Ref}{1024\ bits}}{\text{Temperature coefficient}} \qquad (1)$$

The equation for the calculation of TDS starts from obtaining the electrical conductivity read by the sensor which will influence the TDS. Equation two includes the TDS value obtained from the EC value calculated in equation 2:

$$Tds = (133.42^{EC} - 255.86 * EC * EC + 857.39 * EC) * 0.5 \qquad (2)$$

After that, the data is sent by means of a serial string to be received by the labVIEW® interface and then the values are sent by means of the client.connect (server,80) and client.print commands to the ThingSpeak® IOT silver form interface.

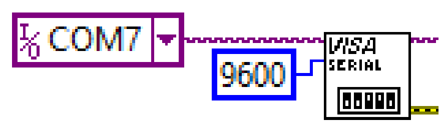
2.5 LabView code for monitoring interface

The following is an explanation of the parts of the block code made for the reception of data sent by the HC-06 module. It is divided into X parts

2.5.1. Selection of port and baud rate:

The baud rate is selected according to what is configured in the card code and the port according to the device as shown in Figure 5.

Figure 5. Part 1 blocks.



Source: Own.

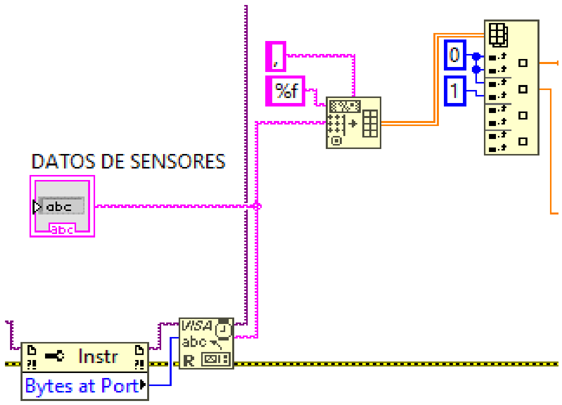
2.5.2. Division of sent data:

A block is implemented that separates data according to the selected character, in this case a comma (",") is used to separate the data sent through Bluetooth. Then they are sent to a vector to be organized in order of arrival as shown in Figure 6.

2.5.3. Data visualization by indicators for the user:

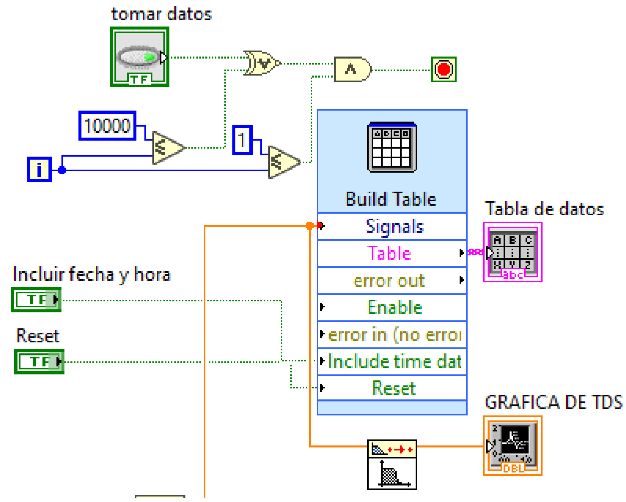
As can be seen in Figure 7, the data obtained in the vector by order, which are connectors to indicators for the user, are divided between TDS and TEMPERATURE °C.

Figure 6. Part 2 blocks.



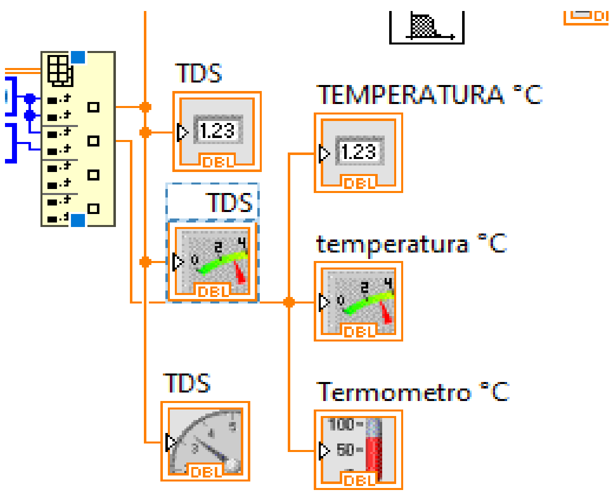
Source: Own.

Figure 8. Second part 3 blocks.



Source: Own.

Figure 7. Part 3 blocks



Source: Own.

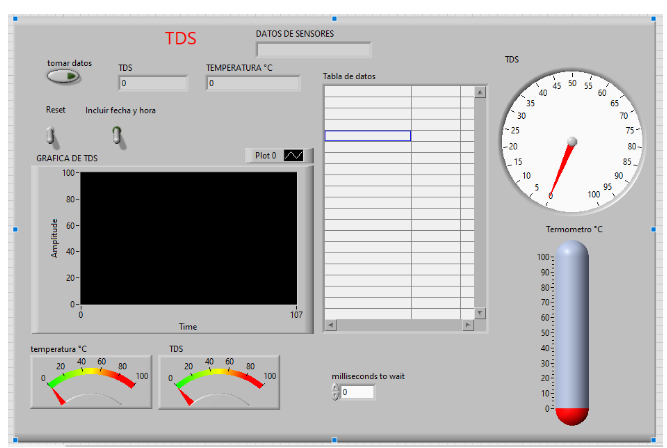
2.5.4. Data collection activation to display data with a configurable time and date:

Boolean button is configured to define the data collection activation, together with another Boolean button to include the date and time in an organized table, then the data is sent to a graph to show the trend of the values for the time established since the data collection is activated, as shown in Figure 8.

2.5.5. Organization of displays in the front-end of the interface design:

As can be seen in Figure 9, the indicators were organized in such a way that it was easy to indicate the behavior of the system.

Figure 9. Prototype interface designed for monitoring data sent via Bluetooth.

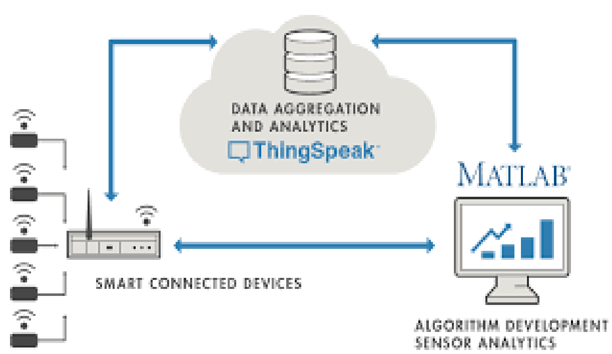


Source: Own.

2.6. Selection of IOT platform for receiving data on the website

The ThingsSpeak page contains its own format where it organizes the data in a table of connected points according to the time that is running, it was decided to send the TDS data and the temperature in °C and °F. Along with this, a user was created which allows exclusive control of the data received, a user and a password are created which also has the code in the initialization of libraries and variables, you can see the operation in Figure 10 [15].

Figure 10. Data flow for the ThingSpeak interface



Source: Own.

3. Results and discussion

The system developed here to measure the conductivity of water, is a technological contribution and the implemented technique has the advantage of allowing continuous monitoring in real time without user intervention, prioritizing the automation of the measurement for an isolated environment, in order to offer an alternative industrial sectors the low cost system for the analysis and monitoring of water in its electrical conductivity. Next, the values obtained by the measurements made with the main TDS sensor with respect to various water samples will be shown. After investigation, the E1 portable TDS &EC METER sensor was used as a measurement reference. This was established as the standard sensor for measurement comparison. It was taken into account that the standard sensor has the characteristics shown in Table 2.

Table 2. Characteristics of the E1 portable TDS &EC METER sensor

Parameter	*Range*	*Accuracy*	*Resolution*
Conductivity	0-9999 ppm (TDS)	±2%	1 ppm
Temperature Celsius	0.1-80.0°C	±2%	0.1 °C
Temperature Fahrenheit	32.0-176.0° F	±2%	0.1 °C

Source: Own.

Then, 4 water samples were obtained from the water laboratories located at the Universidad de los Llanos, which were: pure water, distilled water, type 1 water and residential tap water. Performing the measurements with the project sensor together with the standard sensor, the following values were obtained as shown in Tables 3, 4, 5, and 6 in a short period of time, due to the constancy of the ambient temperature.

Analyzing the accuracy of the prototype sensor with the standard, for each measurement the most constant value of TDS and Temperature was taken and the percentage relative error (RE) was calculated. Equation 3 was calculated for TDS and equation 4 for pure water temperature.

$$ER\ TDS\ pure\ water = \frac{(6-5)\ ppm}{5\ ppm} * 100\% = 20\% \quad (3)$$

$$ER\ pure\ water\ temperature = \frac{(29-29{,}3)\ °C}{29{,}3\ °C} * 100\% = 1.02\% \quad (4)$$

Equation 5 was calculated for TDS and equation 6 for distilled water temperature.

$$ER\ TDS\ destilled\ water = \frac{(5-2)\ ppm}{2\ ppm} * 100\% = 150\% \quad (5)$$

Table 3. Values measured with both sensors for pure water.

Pure water				Distilled water			
Sensor Pattern		Prototype Sensor		Sensor Pattern		Prototype sensor	
Temperature (Celcius)	TDS (ppm)	Temperature (Celcius)	TDS (ppm)	Temperature (Celcius)	TDS (ppm)	Temperature (Celcius)	TDS (ppm)
29.3	6	28.59	6	29,3	2	29,53	5
29.3	7	29	6	29,3	3	29,81	5
29.3	5	29	6	29,3	3	29,81	5
29.3	5	29	6	29,3	3	29,81	5
29.3	5	28.59	6	29,3	3	29,81	5
29.3	5	28.59	6	29,3	2	29,81	5
29.3	5	28.59	5	29,3	2	29,81	5
29.3	7	28.59	5	29,3	3	29,81	5
29.3	6	29	5	29,3	2	29,81	5
29.3	7	29	5	29,3	3	29,61	5

Source: Own.

$$ER\ destilled\ water\ temperature = \frac{(29.81 - 29.3)\ °C}{29.3\ °C} * 100\% = 1.74\% \quad (6)$$

Equation 7 was calculated for TDS and equation 8 for Type 1 water temperature.

$$ER\ TDS\ tipe\ 1\ water = \frac{(5-3)\ ppm}{3\ ppm} * 100\% = 66\% \quad (7)$$

$$ER\ Type\ 1\ water\ temperature = \frac{(29.63 - 30{,}5)\ °C}{30{,}5\ °C} * 100\% = 2.85\% \quad (8)$$

Analyzing the values in percentage in Table 5, it is evident that according to the characteristics shown in Table 1 for the prototype sensor, the error range is exceeded above ± 10% F.S. (25°C) due to the temperature difference obtained in the samples which exceeds 25°C, however, the values analyzed for the samples are values close to 0, so their difference for the analysis of water type is of great impact. For a sample with elevated TDS values, residential tap water was used for measurement and the following Table 6 was obtained.

Table 4. Values measured with both sensors for pure water.

Water type 1			
Sensor Pattern		Prototype Sensor	
Temperature (Celcius)	TDS (ppm)	Temperature (Celcius)	TDS (ppm)
30,5	3	25	5
30,5	2	29,63	6
30,5	3	29,63	5
30,5	3	29,63	5
30,5	3	29,63	5
30,5	3	29,63	5
30,5	3	29,63	5
30,5	3	29,63	5
30,5	3	29	5
30,5	3	29	5

Source: Own.

Table 5. Percentage errors

% Error / Water Type	Distilled Water	Pure Water	Water Type 1
TDS	20 %	150 %	66%
Temperature	1.02%	1.74 %	2.85%

Source: Own.

Table 6. Percentage errors

Residential tap water			
Sensor Pattern		Prototype Sensor	
Temperature (Celcius)	TDS (ppm)	Temperature (Celcius)	TDS (ppm)
28,5	41	28,8	39
28,5	41	28,8	41
28,5	41	28,8	41
28,5	41	28,8	41
28,5	41	28,8	41
28,5	41	28,8	41
28,5	41	28,8	41
28,5	41	28,8	41
28,5	41	28,8	41
28,5	41	28,8	41

Source: Own.

Performing the same calculations, equations 9 and 10 show the improvement in measurement by the prototype sensor calibrated with equations 1 and 2.

$$ER\ TDS\ tap\ water = \frac{(41-41)\ ppm}{41\ ppm} * 100\% = 0\% \quad (9)$$

$$ER\ Type\ 1\ water\ temperature = \frac{(28{,}8-28{,}5)\ °C}{28{,}5\ °C} * 100\% = 1.05\% \quad (10)$$

The interface was modified to include the range of values intended to identify water quality in the maximum TDS range of 0 < 1000 ppm, with the range graph established by the United States Environmental Protection Agency (US EPA) [12] with the option to take time and date stamped data for continuous monitoring specified by the user, a button was added to initialize the labVIEW system and another button to reset the displayed data, this is evidenced in Figure 11.

The ThingSpeak interface was configured for a mobile app and web page as shown in Figure 12.

For the final assembly, a two-part waterproof plastic container was used, the main deep container with dimensions 15x7x4 cm and top lid to seal it. It is large enough to contain the system battery. The conditioning circuit of the TDS meter sensor and DS18B20 sensor together with the built-in bluetooth module. To ensure the floating of the isolated system, icopor material was used by dividing one layer for the battery and together with the second layer on top to hold the main circuit as evidenced in Figure 13.

As expected, the system remained stable monitoring and sending values tested for several days, the important thing is to take into account the network access in the Arduino programming for the key and password of the network, since the bluetooth connection is established from the interface shown in Figure 11.

4.Conclusions

The accuracy of the chosen prototype sensor has its ideal performance within the range different from 10% of the minimum value 0 ppm and maximum, 1000 ppm, being ideally implemented for the monitoring of water to be treated industrially for consumption or food production.

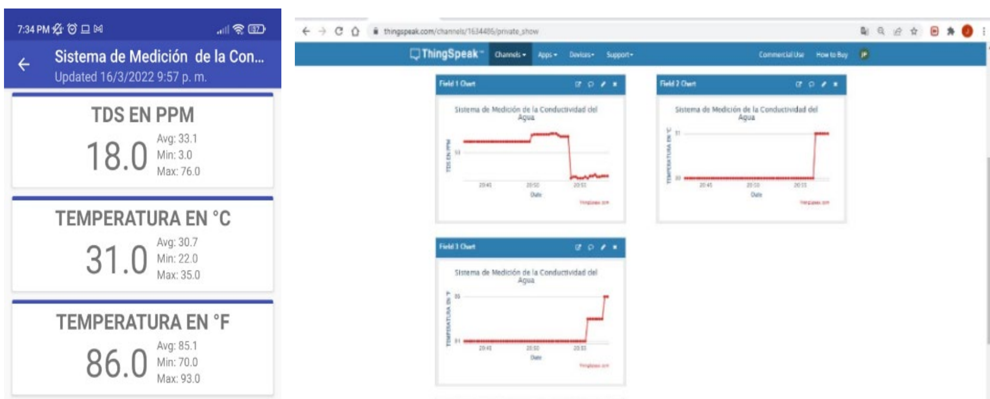
The implemented system is effective in measuring the ranges established in the interface according to the US EPA (US Environmental Protection Agency) which establishes broad ranges with sections of 100 ppm or TDS for water quality level change.

The implementation of two different communications (bluetooth, wifi) for data transmission provides a more robust system because if one communication system fails, it can be supported by the other communication system.

Figure 11. Interface for continuous monitoring process.

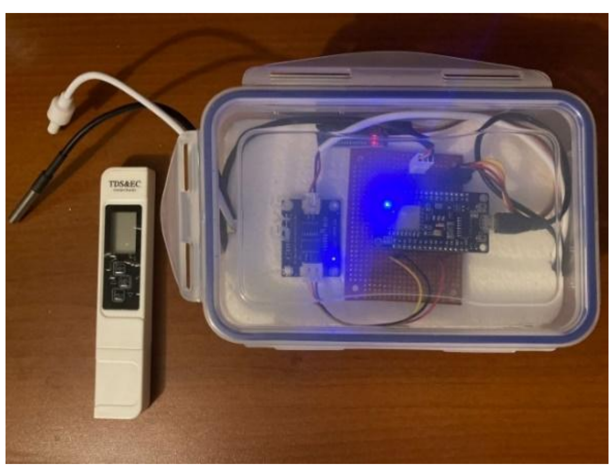
Source: Own.

Figure 12. Interface for continuous monitoring process.



Source: Own.

Figure 13. Isolated system assembly next to the master sensor.



Source: Own.

Using the prototype it is possible to see the characteristics of the irrigation water for the plants that are currently used and thus be able to make corrective measures to improve the quality of the water.

Regarding the accuracy of the monitored data, it is recommended to have the physical limitations of the chosen sensor and a good connection to an internet network for the transmission of the ESP2866 card.

References

[1] S. S. Muñoz Lucas and R. Sánchez García, El agua en la industria alimentaria. Madrid, 2016.

[2] Y. Garc, C. Hidrogr, and O. Garc, "Manuscrito aceptado Manuscrito aceptado," vol. 24, no. 1, pp. 1-23, 2021.

[3] C. Wong-Arguelles, Calidad del agua de los manantiales del humedal natural "Ciénega de Tamasopo," quality of the wellsprings from the natural wetland, Cienega de Tamasopo ", vol. 0, no. 6. 2021. https://doi.org/10.24850/j-tyca-2021-06-01

[4] M. Basterrechea, "Concentración de nutrientes: TDS, EC y PPM, ¿Cuál es la diferencia?," 2017. https://www.hidroponiacasera.net/tds-ec-ppm/

[5] L. S. Torres-Valenzuela, A. Sanín-villarrea, A. Arango-Ramírez, and J. A. Serna-Jiménez, "Caracterización fisicoquímica y microbiológica de aguas mieles del beneficio del café," Ion, vol. 32, no. 2, pp. 59-66, 2019. https://doi.org/10.18273/revion.v32n2-2019006

[6] Y. Marca, R. Agudelo-Valencia, S. Garcés-Polo, and M. Peña, "Evaluación de la electrocoagulación con electrodos de grafito como alternativa para el tratamiento de aguas residuales," Inventum, vol. 16, no. 31, pp. 61-70, 2021. https://doi.org/10.26620/uniminuto.inventum.16.31.2021.61-70

[7] D. Rairán Antolines, Y. Olarte, and C. Peñuela, "Diseño y construcción económica de sensores, un aporte a la industria y a la academia," Ingeniería, vol. 8, no. 1, pp. 50-57, 2003.

[8] J. A. Flórez, D. Márquez Méndez, S. Burgos Núñez, G. Enamorado Montes, and J. Marrugo Negrete, "Productos farmacéuticos y de cuidado personal presentes en aguas superficiales, de consumo córdoba, Colombia.," Investig. Agrar. y Ambient., vol. 12, no. 2, pp. 179-197, 2021. https://doi.org/10.22490/21456453.4231

[9] S. E. Campaña Bastidas and J. M. Londoño Pelaéz, "Estudio de redes de sensores y aplicaciones orientadas a la recolección y análisis de señales biomédicas," Gerenc. Tecnol. e Informática, vol. 12, no. 2, pp. 85-99, 2013.

[10] A. Rojas Lucero, "Diseño y Fabricación del Sensor Para Medición de la Conductividad Eléctrica en Aguas Superficiales," Universidad Militar Nueva Granada, 2019.

[11] C. Rodrigo Herrera, P. Pacheco Mollinedo, M. E. Orihuela, M. L. Piñeros, and E. Cobo, Guía de monitoreo participativo de la calidad de agua, 1st ed. Quito: Unión Internacional para la Conservación de la Naturaleza, 2018.

[12] R. Ríos Hernández, "La Agricultura de Precisión. Una necesidad actual," Ing. Agrícola, vol. 11, no. 1, 2021, [Online]. Available: https://www.redalyc.org/journal/5862/586269368010/html/

[13] M. Hayashi, Temperature-Electrical Conductivity Relation of Water for Environmental Monitoring

and Geophysical Data Inversion, 1st ed. Alberta, Canada: University of Calgary, 2004. https://doi.org/10.1023/B:EMAS.0000031719.83065.68

[14] T. S. Light, S. Licht, A. C. Bevilacqua, and K. R. Morash, "The Fundamental Conductivity and Resistivity of Water The Fundamental Conductivity and Resistivity of Water," no. January, pp. 1-5, 2019. https://doi.org/10.1149/1.1836121

[15] N. F. Junior, A. A. A. Silva, A. E. Guelfi, and S. T. Kofuji, "Performance evaluation of publish subscribe systems in IoT using energy efficient and context-aware secure messages," J. Cloud Comput. Adv. Syst. Appl., vol. 11, no. 6, pp. 2-17, 2022. https://doi.org/10.1186/s13677-022-00278-6