Learning embedded systems through a water quality monitoring system in riverside communities with Arduino

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Fabricia Ferreira Neves[1], Amanda Vitória Lima dos Santos[2], Claudio Enrique Marinho dos Santos[3], João Victor da Silva Reis[4], Vitor Bremgartner da Frota[5] and Julieuza de Souza Natividade[6]

ABSTRACT

Water is a natural resource, whether as a biochemical component of living beings, as a way of life for various plant and animal species, as a representative element of social and cultural values and as a production factor for various consumer goods. However, in recent years, with population growth and exacerbated industrial expansion, water quality has been compromised, harming human health and affecting communities that need it to survive, such as riverside communities located in the Brazilian state of Amazonas. Geographic isolation and the lack of public policies for these communities make it difficult to access essential services, such as health, education, electricity, basic sanitation, communication technology, among others. In this context, the teaching of embedded systems technology can be redirected to water monitoring and serve as an auxiliary tool in the verification of its quality, from the verification of total dissolved solids (TDS) and pH, to provide health, safety and guarantee that the water consumed by these populations is suitable for daily use. Therefore, in this work we chose to elaborate a didactic project using Arduino and sensors that consists of a prototype that helps in this measurement. In this way, we built a prototype, integrating low-cost sensors for real-time monitoring of water quality, which is capable of measuring its chemical parameters, so that communities that do not have the necessary information to classify the water as potable, can have knowledge of the state of the water they consume.

Keywords: Water quality, Riverside communities, Monitoring, Chemical parameters, Embedded systems.

[1] Federal Institute of Education, Science and Technology of Amazonas: Manaus Industrial District Campus
Specialist in the Environment and its Technologies
E-mail: FSNeves2011@gmail.com
LATTES: https://lattes.cnpq.br/8527170330142911
[2] Federal Institute of Education, Science and Technology of Amazonas: Manaus Industrial District Campus
Intermediate Technical Course in Industrial Mechatronics
E-mail: 2021314170@ifam.edu.br
[3] Federal Institute of Education, Science and Technology of Amazonas: Manaus Industrial District Campus
Intermediate Technical Course in Industrial Mechatronics
E-mail: 2021316648@ifam.edu.br
[4] Federal Institute of Education, Science and Technology of Amazonas: Manaus Industrial District Campus
Intermediate Technical Course in Industrial Mechatronics
E-mail: 2021314400@ifam.edu.br
[5] Federal Institute of Education, Science and Technology of Amazonas: Manaus Industrial District Campus
Doctor of Informatics
E-mail: vitorbref@ifam.edu.br
LATTES:http://lattes.cnpq.br/6100146230873494
ORCID: https://orcid.org/0000-0003-1073-756X
[6] Federal Institute of Education, Science and Technology of Amazonas: Manaus Industrial District Campus
Master's in Education
E-mail: julieuza.natividade@ifam.edu.br
LATTES: http://lattes.cnpq.br/2906755122056860
ORCID: https://orcid.org/0000-0003-4856-5054

INTRODUCTION

Water is an essential resource for the existence of any life on Earth. Water is available worldwide and meets the main needs of humanity, that is, residential, domestic, agricultural and industrial needs. In recent years, water quality has been negatively impacted by the increase in human population, which has led to the expansion of cities, increased industrialization and the uncontrolled use of natural resources [4]. The result was the production of a large amount of domestic and industrial sewage dumped directly into urban water ecosystems [3].

Around 80% of the water resulting from human activities is released into water bodies without any pollution removal. Waste such as organic matter, heavy metals, pesticides, pharmaceutical and personal care products, nanoparticles, plastics and pathogens are among the pollutants of greatest worries [5]. One of the main difficulties in removing these pollutants is the lack of economic resources necessary for the creation and application of remediation technologies [1]. A standard and effective method of assessing water quality is the monitoring of chemical and physical parameters in the aquatic environment.

An innovative way to monitor these parameters is through sensors that capture the necessary information, record and send everything in real time [2]. Therefore, for this work a prototype was developed, using low-cost sensors to monitor water quality. This prototype is capable of measuring the parameters of total dissolved solids (TDS) and pH. After this measurement, the community will have important and necessary information to identify whether the water they are consuming is safe for consumption or not.

At the same time, in this work we had the integration of 3 High School students together with 1 student specializing in Environment and Technologies, in which the developed system allowed better learning about embedded systems applied to environmental technologies. We combine principles of maker culture, interaction between students at different levels of education and Project-Based Learning (PBL), as presented in [6], in order to build this system.

METHODOLOGY

CHOOSING THE STUDY AREA

In our study, we chose the municipality of Coari, which has an area of 57,529.70 km² and is located 364 km from the capital of the Brazilian State of Amazonas, Manaus. Despite being located in the Amazon river basin, the largest in Brazil and the world, Coari has several vulnerable locations, where there is no access to drinking water and sanitation, something that is considered very important for the population's health. The city has a high rate of residents who live on the banks of rivers and creeks, and these people do not have access to drinking water. Many consume water from the same place where they usually dump their waste and other people look for water further away from where they live. Fig. 1 shows the location of Coari on the map of Amazonas, in South America, extracted from the Google Maps website. Coari is bathed by the Solimões River, which is part of the Amazon River.

Figure 01: Location of Coari in the Brazilian State of Amazonas (pin on the left). The starred mark (pin on the right) is the location of Manaus.

Source: Authors (2023).

In turn, Fig. 2 shows an example of a riverside community in Coari, as well as a child taking water from the Solimões River for consumption and a woman washing clothes and dishes in the river.

Figure 02: Riverside communities in Coari; Child taking water from the Solimões River for consumption; Riverside woman washing clothes and dishes with river water.

Source: Authors (2023).

Furthermore, water obtained from the river is also used for drinking. Fig. 3 shows by the color of the water, which is also an analysis factor, that this water is not suitable for consumption. The situation becomes even more difficult between the months of May and September each year, when rivers drop their water levels, a period called drought.

Figure 03: Water with a yellowish color used for human consumption, in a riverside community in Coari.

Source: Authors (2023).

MATERIALS

The basic structure of the system consists of sensors with the ability to measure water parameters, one or more microcontrollers that will read the analog signals and transmit them to a computer for data visualization. Therefore, the system has two sensors for measuring pH and TDS, as shown in Table 1.

Table 01: Materials used.

	Materials	*Model*	*Description*
1	Arduino	MEGA2560	The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a powerjack, an ICSP header, and a reset button
2	pH sensor	PH-4502C	The Arduino pH Sensor is a functional and practical sensor developed especially to work in conjunction with microcontrollers.
3	TDS sensor	OEM	A TDS meter measures the total number of dissolved solids such as salts, minerals, and metals in water. As the number of dissolved solids in water increases, the conductivity of the water increases, which allows us to calculate total dissolved solids in parts per million, ppm (mg/L).

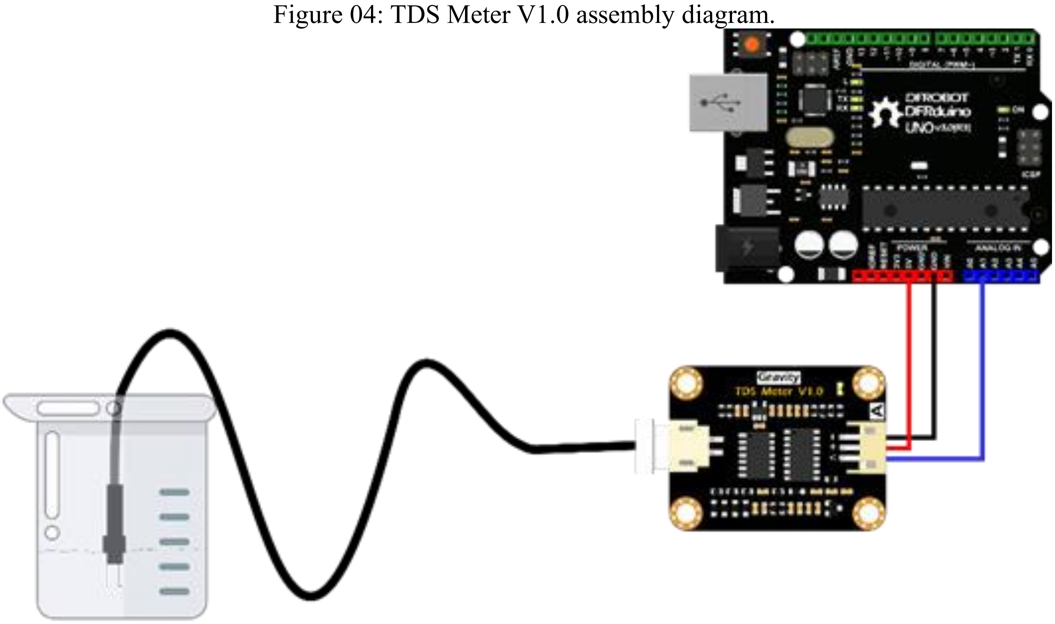
Source: Authors (2023).

APPLICATION DEVELOPMENT

The water quality monitoring system was developed through the integration of knowledge in the areas of Programming, Embedded Systems and Environment, with interaction and collaboration between teachers and students of Technical High School in Mechatronics, from the Federal Institute of Amazonas Campus Manaus Distrito Industrial (IFAM CMDI). The Specialization in Environment and Technologies student was responsible for collecting water from riverside communities in Coari and recording these visits.

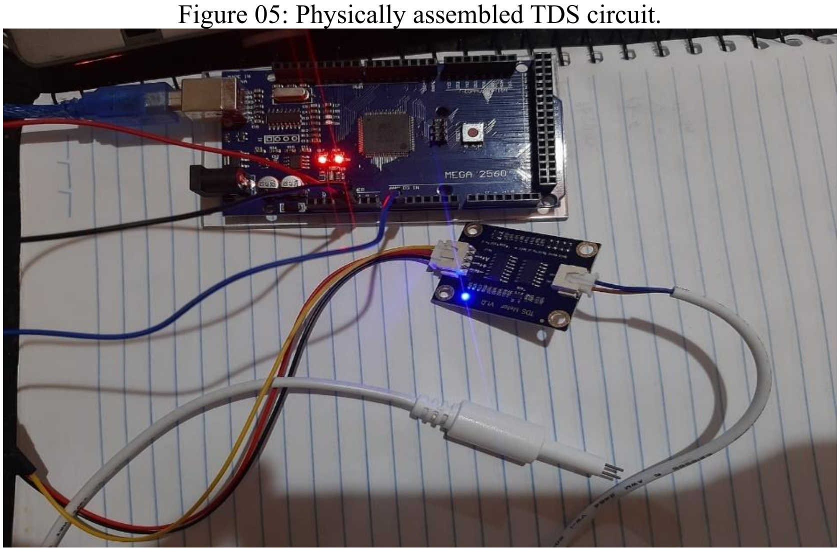
Fig. 4 shows the TDS meter assembly diagram. Fig. 5 shows the physically assembled circuit. In turn, Fig. 6 shows the schematic diagram of connecting the pH sensor to the Arduino and in Fig. 7 there is the physically assembled Arduino pH sensor connection diagram.

Figure 04: TDS Meter V1.0 assembly diagram.



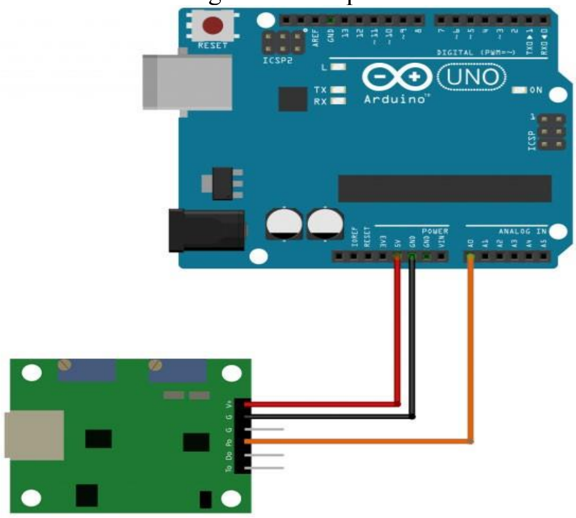
Source: Authors (2023).

Figure 05: Physically assembled TDS circuit.



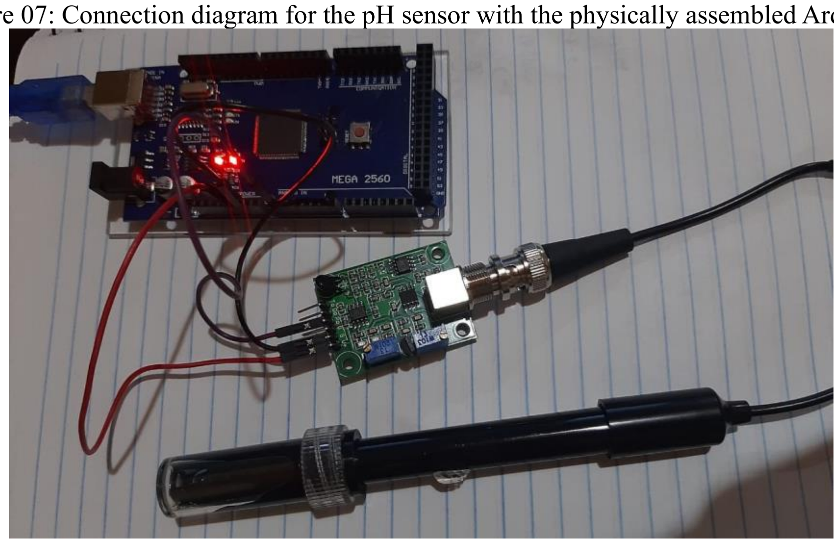
Source: Authors (2023).

Figure 06: Connection diagram for the pH sensor with the Arduino.



Source: Authors (2023).

Figure 07: Connection diagram for the pH sensor with the physically assembled Arduino.



Source: Authors (2023).

After assembling the circuit, the programming was developed in the Arduino IDE, using sensor libraries based on the C++ language, after identifying the input data, processing and output procedures, as shown in Fig. 8.

Figure 08: Code used to calibrate the TDS meter and to calibrate the pH sensor.

```
#include <EEPROM.h>
#include "GravityTDS.h"

#define TdsSensorPin A1
GravityTDS gravityTds;

float temperature = 25,tdsValue = 0;

void setup()
{
    Serial.begin(9600);
    gravityTds.setPin(TdsSensorPin);
    gravityTds.setAref(5.0);
    gravityTds.setAdcRange(1024);
    gravityTds.begin();
}

void loop()
{
    gravityTds.setTemperature(temperature);
    gravityTds.update();
    tdsValue = gravityTds.getTdsValue();
    Serial.print(tdsValue,0);
    Serial.println("ppm");
    delay(1000);
}
```

```
int ph_pin = A0;

void setup() {
  Serial.begin(9600);
  }

void loop() {
  int measure = analogRead(ph_pin);
  Serial.print("Measure: ");
  Serial.print(measure);

  double voltage = 5 / 1024.0 * measure;
  Serial.print("\tVoltage: ");
  Serial.print(voltage, 3);

  float Po = 7 + ((2.5 - voltage) / 0.18);
  Serial.print("\tPH: ");
  Serial.print(Po, 3);

  Serial.println("");
  delay(2000);
}
```

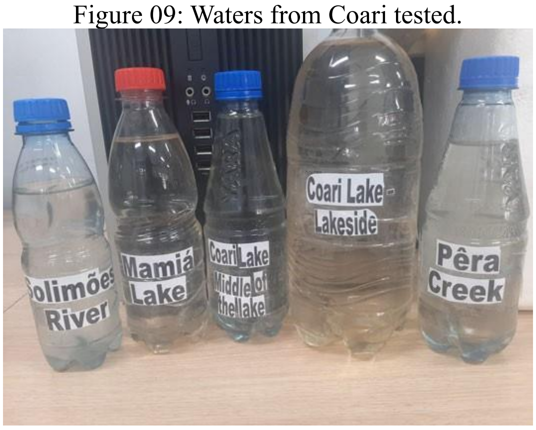
Source: Authors (2023).

RESULTS

TOTAL DISSOLVED SOLIDS (TDS)

Due to an inversion of values caused by the sensor, the measurement was made by comparing the values of drinking mineral water and those of water collected in the rivers, creeks and lakes of Coari, whose waters are identified in the bottles in Fig. 9. It was observed that the value of the mineral water did not change at any time during the measurements, which did not occur in the water collected, the measurement was made as shown in Table 2.

Figure 09: Waters from Coari tested.



Source: Authors (2023).

Table 02: Values obtained for total dissolved solids in the analyses.

Collection Points	*Total Dissolved Solid Values*									*Reference*
Mineral Water	18 ppm	18 ppm	18 ppm	18 ppm	18 ppm	18 ppm	18 ppm	18 ppm	18 ppm	Ordinance GM/MS No. 888, May 4th, 2021.[7]
Pêra Creek	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	
Coari Lake – Middle of the Lake	2 ppm	2 ppm	2 ppm	2 ppm	2 ppm	2 ppm	2 ppm	2 ppm	2 ppm	
Coari Lake – Lakeside	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	
Mamiá Lake	3 ppm	3 ppm	3 ppm	3 ppm	3 ppm	3 ppm	3 ppm	3 ppm	3 ppm	
Solimões River	34 ppm	34 ppm	34 ppm	34 ppm	34 ppm	34 ppm	34 ppm	34 ppm	34 ppm	

Source: Authors (2023).

As the sensor inverts the values, the following subtraction is made: 18 - 5 = 13, where we assign 5 to the value of mineral water, the base value determined by GM/MS ordinance nº 888 [7] and 13 to the value of Pêra Creek water. From this perspective, it is possible to observe that there is a notable difference between the values of mineral water and water from Pêra Creek, water that is used daily by riverside communities. When applying the same logic used in the previous measurement, we have: 18 - 2 = 16. In this way, we attribute 2 to the value of mineral water and 16 to the value of water from Lake Coari (middle of the lake). From this analysis, we see that the water in the middle of Lake Coari is not suitable for consumption.

Thus, the values were inverted, performing the subtraction: 18 - 5 = 13. Where 5 was attributed to the value of mineral water and 13 to the value of water of Lake Coari (Lakeside). The value of water from Mamiá Lake was assigned 15 and we assigned 3 to the value of mineral water. With this, it is possible to observe that there is a notable difference between the values of mineral water and the values of water from the Lake Coari (Lakeside) and Mamiá Lake, water that is used daily by riverside communities.

In the latter case, it is possible to observe an atypical occurrence in the measurement when it is compared to previous measurements, as the ppm value of the water collected in the Solimões River was higher (34 ppm) than the value of the mineral water. Thus, it is clear that even using 18, which is a value that did not change during any measurement, the value remained within the range of 2 to 5 in the other 4 locations, a range established by the National Health Surveillance Agency (ANVISA), an Brazilian agency institution whose institutional purpose is to promote the protection of the population's health, through sanitary control of the production and consumption of products and services subject to sanitary surveillance, including environments, processes, inputs and technologies related to them. Therefore, it is possible to notice the great difference in values between mineral water and water from the Solimões River. This analysis indicates that this water is not within the limit permitted by legislation, and is therefore considered unfit for human consumption.

HYDROGENION POTENTIAL (PH)

PH can be considered one of the most important environmental variables, and is one of the most difficult to interpret, due to factors such as pollution. According to CONAMA Resolution No. 357 [8] it establishes that for the protection of aquatic life the pH must be between 6 and 9.

When adding all the values and making an average, the values obtained are shown in Table 3. The pH of Lake Coari (Lakeside), is on average 5.88, the average pH of Lake Coari, in the middle, is 6.42, the average pH of Mamiá Lake is 6.69, the average pH of the Solimões River is 6.27 and the average pH value of Pêra Creek is 5.76.

Table 03: pH values obtained in the analyses.

CollectionPoints	*Coari Lake – Lakeside*	*Coari Lake – Middleof the Lake*	*Mamiá Lake*	*Solimões River*	*Pêra Creek*
Hydrogenion Potential (pH)	5.73	6.19	6.62	5.74	5.98
	5.53	6.32	6.64	6.41	6.13
	5.53	6.86	6.58	5.04	6.10
	5.53	6.40	6.56	6.16	5.43
	5.55	6.35	5.95	6.92	5.61
	5.34	6.09	5.90	6.82	6.02
	5.79	6.53	6.26	6.71	6.14
	5.08	5.79	6.70	6.21	5.74
	5.78	6.54	6.37	6.08	6.55
	5.33	6.12	6.70	5.60	5.73
	5.59	6.32	8.68	6.37	6.16
	5.27	6.20	7.19	6.25	5.85
	5.81	6.17	6.61	6.33	5.99
	5.48	6.27	6.80	5.97	6.05
	5.55	6.29	6.51	6.51	6.07
	5.55	6.45	6.52	6.09	6.08
	5.88	5.95	6.28	6.78	5.49
	6.43	7.15	7.00	6.71	6.24
	6.16	6.36	6.75	6.11	5.84
	6.59	6.92	6.76	6.39	6.13
	5.82	6.51	7.35	5.93	5.97
	7.07	6.67	6.74	6.16	5.89
	6.04	6.57	6.33	6.12	6.12
	6.92	6.58	7.57	6.23	6.21
	6.35	6.77	6.45	6.59	6.17
	6.79	6.68	6.86	6.53	5.73
	6.51	6.55	6.19	6.67	6.27

Source: Authors (2023).

CONCLUSIONS

This article demonstrated an action that reconciled an application of embedded systems through the technologies involved and the environment. This connection between different areas allows the monitoring of the quality of these waters, which can contribute to environmental sustainability by efficiently monitoring water resources. In the future, these sensors can be installed at strategic points with an Internet connection, sending data to online platforms, thus facilitating researchers, public bodies and the general population to quickly access this information, identifying problems, and taking immediate measures in order to mitigate possible tragedies caused by the lack of adequate treatment of water consumed by riverside communities. It is important to highlight that the implementation of this technology requires financial investments, infrastructure and technical training.

Furthermore, this work brought together students from different areas and levels, involving students from Technical High School in Mechatronics and Postgraduate Studies in Environment and Technologies. This contact allowed for a great sharing of knowledge, obtaining relevant learning for the job market and academic training, regardless of educational level.

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