Innovation in Low-Cost Sensor for Water Turbidity Assessment

Halana Santos Lisboa[1]*, Mariana Pires Maria[1], Vanessa Cristine Silva Santos[1], Michael Santana Reis[2], Gilderlan Oliveira Rodrigues[2]
[1]Tiradentes University; [2]Federal Institute of Sergipe; Aracaju, Sergipe, Brazil

This work emphasizes the importance of monitoring water quality through a low-cost turbidity sensor to support environmental management. Using LDR sensors and an Arduino, the project determines the ideal wavelength and establishes the calibration curve. The sensor operates automatically, performing color scanning and selecting the wavelength most sensitive to variations in water turbidity. Data analysis revealed a calibration curve with a coefficient of determination (R^2) of 0.995, highlighting the sensor's high precision. Turbidity quantification is achieved through nephelometric (90°) and turbidimetric (180°) methods, optimizing sensor configuration and wavelength to obtain the best measurements.
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Water is essential for life. Although two-thirds of the Earth's surface is covered by water, only 2.5% of it is freshwater. Of this fresh water, 68.9% is found in glaciers and polar ice caps, 29.9% is groundwater, 0.9% is found in soil moisture and swamps, and only 0.3% is found in rivers and lakes, available for use [1]. In this context, Brazil holds a privileged position compared to other countries, boasting the largest freshwater reserve in the world, which accounts for 12% of the global total. However, this abundance of water is not evenly distributed throughout the country. The Amazon, for example, is home to one of the largest river basins on the planet, but it is also one of the least populated areas in Brazil.

In contrast, the largest population concentrations in Brazil are found in large urban centers, which are often far from the country's main rivers [2]. The region that suffers most from water scarcity is the Northeastern Semiarid region, where the lack of water results in constant rationing, due to the irregularity of the rainfall regime, affecting both human consumption and socioeconomic development [3]. Therefore, it is essential to implement planning and management measures for available water resources to ensure a continuous supply that meets the population's needs.

Monitoring water quality is one of the main challenges for efficient water management. According to Law No. 9,433/97, this aims to ensure the availability of water with quality standards appropriate for its respective uses. The main parameters analyzed for water quality control include pH, turbidity, electrical conductivity, temperature, and dissolved oxygen. Among these, turbidity stands out as a crucial indicator, as its variation indicates an increase in suspended matter or impurities, thereby affecting the water's clarity [4-6].

The turbidity is an optical property that causes the scattering of light by particles and molecules, preventing light beams from passing through the water. In simpler terms, turbidity indicates the relative transparency of the water. There are several techniques and methods for measuring turbidity in a water sample, but the most accurate are turbidimetry and nephelometry. These methods utilize a light source that shines on the sample, capturing both transmitted and scattered light [7,8].

Turbidimetry is a method for determining turbidity based on the attenuation of a light beam that passes through the sample and reaches a detector positioned 180 ° from the radiation source. On the other hand, in nephelometry,

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Address for correspondence: Halana Santos Lisboa.Avenida Nestor de Melo Pita, 535 - Centro. Amargosa, Bahia, Brazil. Zipcode: 45300000. E-mail: halanalisboa17@gmail.com.

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turbidity is determined by the amount of scattered light that reaches the detector, located 90 ° from the emitting source [9,8].

In the literature, studies have utilized microcontrollers in the construction of turbidimeters. For example, Cardoso (2011) created a turbidity sensor to monitor several water samples, using an LED and a phototransistor that operate in the infrared region. The results indicated that the device was more effective for turbidity values above 100 NTU. In another study, Martins (2012) developed a turbidimeter capable of measuring turbidity between 16 and 4000 NTU to assess the quality of liquid effluents emitted by industries. However, these devices are not suitable for measuring the turbidity of drinking water, which should be maintained at a maximum of 1 NTU [10,11].

In this context, the present work aims to develop a low-cost turbidity sensor capable of measuring water turbidity in real-time and in continuous flow. The sensor will be able to measure levels suitable for human consumption up to higher concentrations, such as those found in industrial effluent disposal.

Materials and Methods

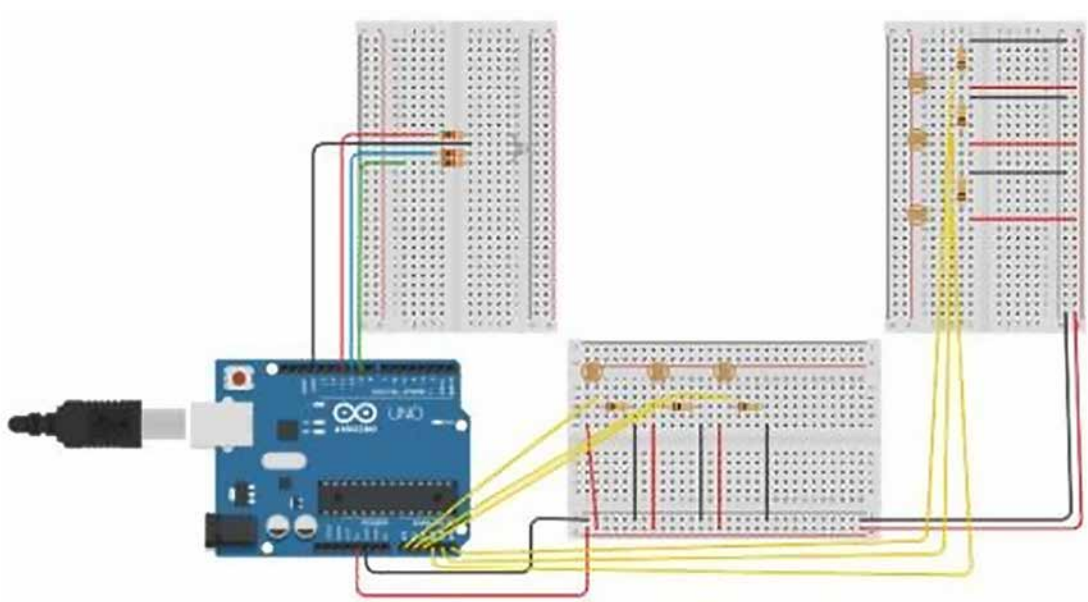
Prototype Design and Materials

The Tinkercad tool was used to design the turbidity sensor. After finalizing the sensor's architecture, the project was further developed on the Tinkercad platform (Figure 1), which streamlined the specification of materials and resources needed to build the prototype. The list of materials used is provided in Table 1.

Table 1. List of components required to assemble the prototype.

Components	Amount
LED RGB	1
LDR	6
Arduino UNO	1
Protoboard	1
Jumpers	24
Resistors de 10kΩ	6
Resistors de 220Ω	3

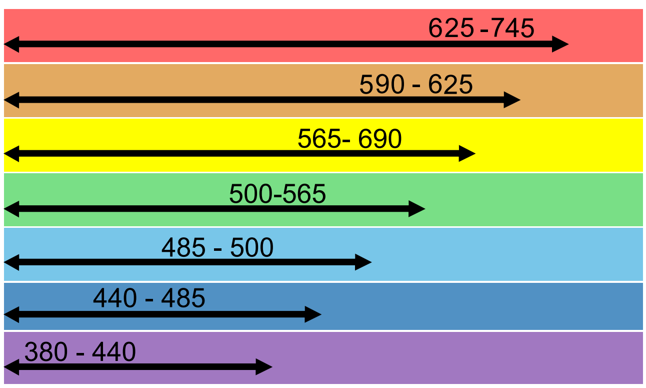
Figure 1. Turbidity sensor design developed in Tinkercad.



Data Acquisition and Analysis with Arduino

To perform data acquisition and analysis, an Arduino was used, programmed with an algorithm that scans the visible light spectrum, covering wavelengths from 380 nm to 745 nm (Figure 2). This range encompasses all colors perceptible to the human eye. The scan starts at 380 nm and gradually increases until reaching 745 nm.

Figure 2. RGB LED colors and related wavelengths.



Using RGB LED in Color Scanning

For color scanning, an RGB (Red, Green, and Blue) LED was used, which includes the three primary colors: red (R), green (G), and blue (B). By combining these colors, the LED can generate any color within the visible spectrum. The luminous intensity of each RGB component can be adjusted from 0 to 255, where 0 indicates no color and 255 represents maximum intensity. This flexibility enables the RGB LED to simulate any color required for spectrum scanning, including the primary colors depicted in Figure 3.

Plotting and Data Analysis

The data collected by the Arduino was processed and plotted using the Arduino IDE's Serial Plotter. This visualization enabled the analysis of the LDR's sensitivity to different wavelengths, offering a detailed understanding of the sensor's behavior under various lighting conditions.

Figure 3. Colors used for initial scanning of the prototype.

BLACK	(0, 0, 0)
WHITE	(255, 255, 255)
RED	(255, 0, 0)
YELLOW	(255, 255, 0)
GREEN	(0, 255, 0)
CYAN	(0, 255, 255)
BLUE	(0, 0, 255)
MAGENTA	(255, 0, 255)

Experimental Procedure

The turbidity samples were organized in ascending order, starting with the lowest NTU value and progressing to the highest. A total of 10 samples were analyzed, with each sample measured three times (in triplicate) to ensure accuracy and minimize experimental error. The sensor was programmed to have the RGB LED scan through 24 different colors, covering the entire spectrum from violet to red. LDR readings were taken at two different angles, 90° and 180°, allowing for a comparative analysis of the sensor's performance in different geometric configurations.

RESULTS AND DISCUSSION

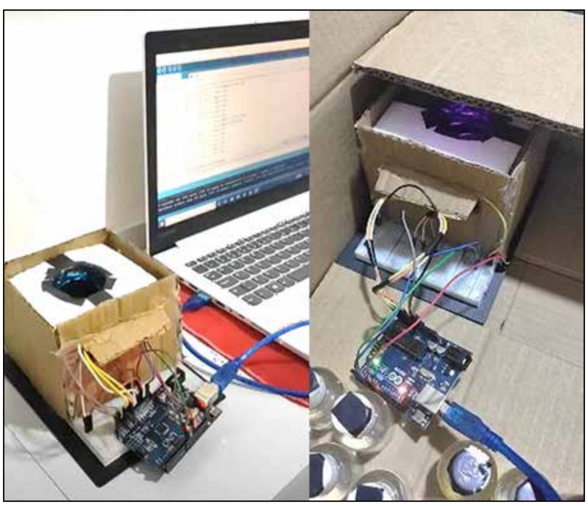
Prototype Assembly

The protection against external light was meticulously designed to ensure the accuracy of the sensor measurements and to minimize interference from ambient light. Styrofoam was chosen as the primary material due to its insulating properties, with an additional layer of cardboard added to reinforce the structure. The components were secured with hot glue, providing durability and stability. Furthermore, the interior of the cover was entirely lined with insulating tape, which was crucial for reducing internal light reflection and preventing it from impacting the sensor readings, thereby ensuring more accurate and reliable measurements. The first version of the prototype is shown in Figure 4.

Impact of Reading Angles

LDR measurements were conducted at two different angles: 90° and 180°. Data analysis revealed that the 90° angle yielded readings with greater sensitivity to wavelength variations (Figure 5, left). This increased sensitivity can be attributed to the more direct interaction between the incident light and the particles suspended in the sample, which enhances the detection of turbidity. In contrast, the 180° configuration exhibited lower sensitivity, likely due to reduced direct interaction with the particles, leading to less accurate readings (Figure 5, right). Therefore, the scan effectively demonstrated the sensor's response to various wavelengths and validated the device's ability to detect turbidity variations accurately.

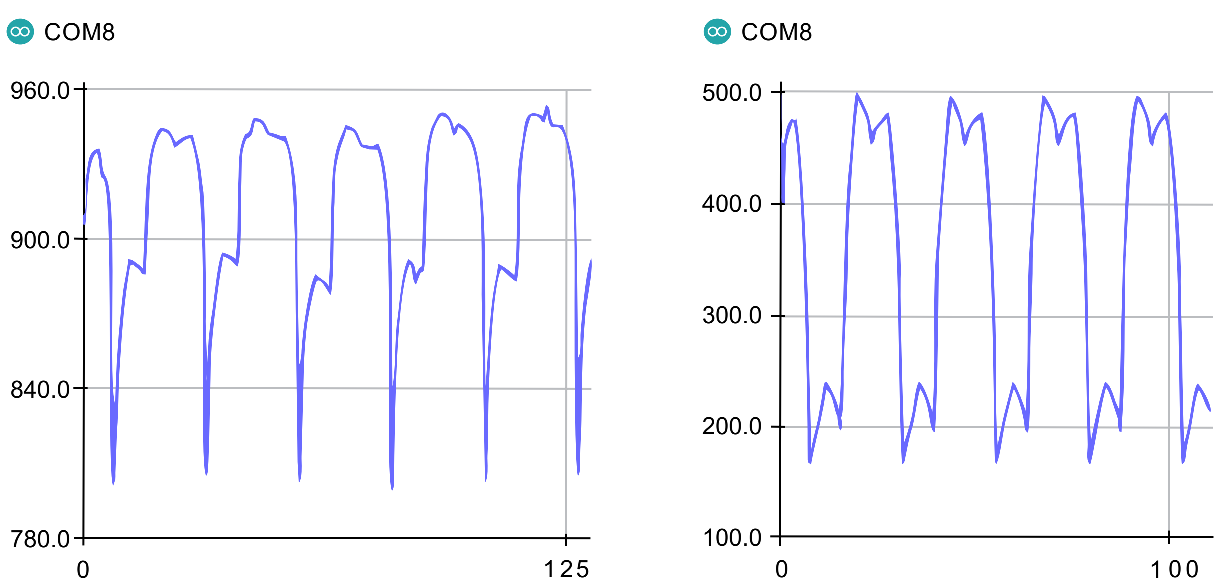
Figure 4. Prototype assembled and protected from external light interference in operation.



Turbidity Sensor Calibration

The turbidity sensor was calibrated using samples with known turbidity values provided by the Sergipe Department of Sanitation (DESO). During the tests, turbidity measurements were taken with red light at a 90° angle to the sensor. For each of the 10 samples, measurements were repeated in triplicate. The average of these readings was calculated and used to create graphs illustrating the relationship between the turbidity values (NTU) and the sensor intensity readings. Additionally, analyzing the samples arranged

Figure 5. Sensitivity reading of LDRs at 90º (left) and 180º (right) during scanning.



in order of increasing turbidity revealed a clear correlation between rising NTU values and the intensity of the sensor readings. This correlation confirms the effectiveness of the calibration method and validates the sensor's capability to deliver consistent and predictable turbidity measurements. The observed linearity in the turbidity graphs further reinforces the reliability of both the sensor and the method used for measuring turbidity variations.

Turbidity Graph Generation and Analysis

The turbidity data were plotted to visualize the relationship between NTU values and the intensity of the readings. The curve that best represented the data distribution was determined using a polynomial equation, as shown in Figure 6. The coefficient of determination (R^2) was calculated to assess the accuracy of the curve fit to the experimental data. The graphical analysis confirmed the validity of the proposed model and demonstrated the sensor's ability to measure turbidity with high accuracy. Consequently, this curve was implemented into the Arduino programming, allowing the sensor to calculate turbidity when a water sample was inserted.

Conclusion

This work developed a low-cost turbidity sensor using Arduino, capable of measuring water turbidity in real-time and in continuous flow. The sensor proved effective in detecting various turbidity levels, achieving an R^2 value of 0.995. The 90° configuration and the use of green light yielded better results for low turbidity values, making it ideal for monitoring drinking water. The economic accessibility of the sensor is a notable advantage, enabling its use in a wide range of applications, from wastewater monitoring to drinking water quality control. Future improvements could include enhancing the color scanning algorithm and exploring the use of additional light sensors to increase measurement accuracy further.

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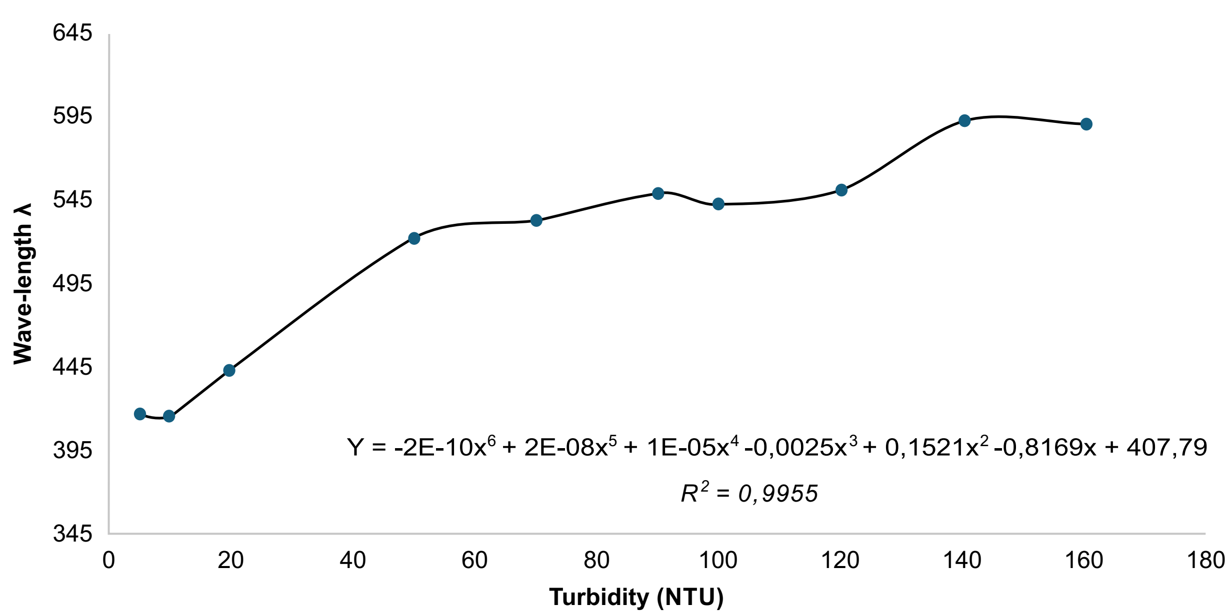
Figure 6. Turbidity sensor calibration curve in red light at 90º.



trust of these institutions, this work would not have been possible.

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