



A Cost-Effective Instrument for Measuring Total Dissolved Solids, Electrical Conductivity and Turbidity – A Step towards Sustainable Development

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ABSTRACT

Water is an indispensable natural resource which is crucial to the sustenance of human, livestock and plants on the earth surface. It is therefore pertinent to ensure its quality is maintained to acceptable standard. This study presents the design and construction of a cost effective portable instrument for measuring total dissolved solids, electrical conductivity and turbidity of water samples. The work was structured under a three-staged framework comprising system design and construction, calibration and performance evaluation. The hardware integrated an Arduino Uno microcontroller, electrical conductivity and turbidity sensors, with a display module. Calibration was conducted using standard buffer solutions prepared using Environmental Protection Agency regulations for total dissolved solids and turbidity. Hexamethylenetetramine was diluted with hydrazine sulphate to produce 4000NTU formazin standard solution which was further diluted to other concentrations for turbidity. Pure sodium chloride was also used to produce 1000ppm and 500ppm standard solutions for total dissolved solids measurement. The calibration was done and the error on the sensors were 0.9% and 0.4% for total dissolved solids 1000ppm and 500ppm respectively, also 12.5% and 5% for turbidity standards of 400NTU and 40NTU respectively. This research fills an important gap in water quality monitoring by providing a cost effective, portable, multi-parameter instrument capable of measuring total dissolved solids, electrical conductivity and turbidity in real time. The work contributes to Sustainable Development Goal 6 by providing an accessible tool for real-time water quality assessment, particularly in resource-limited communities. It is a locally reproducible solution for environmental monitoring, public health protection, and community-based water management.

1. Introduction

Measurement systems are traditionally used to measure physical and electrical quantities, such as mass, temperature, force, pressure, velocity, angular velocity, acceleration, capacitance, and

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voltage [1]. To determine whether the quality of the water is good for use, several aspects including water parameter monitoring must be checked [2]. The contents of these parameters greatly influence whether the water quality is good or not. Salinity is the measure of concentration of salts in water and greater concentration of salts could cause health hazards alongside affecting the taste of the water [3]. Total Dissolved Solids (TDS) include inorganic salts and organic matter dissolved in water, and a TDS level between 300 and 600 mg/l is considered to be good [4]. Water Quality assessment is a necessary exercise to be carried out frequently on surface or underground water bodies, especially when these sources are extracted for domestic use [5].

In this study, an instrument was designed and constructed to measure three water quality parameters; Total Dissolved Solids (TDS), Electrical Conductivity (EC) and turbidity. Designing an instrument to measure specific water quality parameters involve selecting appropriate sensors, integrating them into a cohesive instrument, ensuring accuracy and reliability, and considering deployment in environmental conditions. Inability to properly measure water quality parameters is a major cause of the water crises in many locations especially the rural areas [6]. Having an instrument that can measure such parameters will better inform the society of the necessity to treat such water bodies where necessary and improve on the water use practice [7].

The turbidity sensor detects levels of water turbidity based on the presence of particles, changing the output voltage with increasing turbidity [2]. The TDS sensor uses the electrical conductivity method, where two probes are immersed in a liquid or solution then a signal processing circuit will produce an output that shows the conductivity of the solution [8]. The TDS sensor, is used to detect the number of both organic and inorganic dissolved solid particles in water. Sensor testing is necessary to determine the response of the TDS sensor to changes in water. The sensor is first connected to the Arduino Uno so it can display the analog value and sensor voltage via the Arduino Integrated Development Environment (IDE) serial monitor [9]. A moving charge produces an electrical current, then the meter measures the generated current [4].

1.1 TDS Sensor. The TDS meters (Fig. 1) internally convert the measured current into parts per million (ppm). Light passing through water tends to bend at a particular angle, depending on the effective Refractive Index of water due to dissolved elements. Thus a method of liquid refractometry can be useful in the detection of the variation of salinity/TDS of water [4]. The internal circuit converts this conductivity to an analog voltage (typically 0 – 2.3v) which is proportional to TDS. The analog voltage from the sensor is sent to the Arduino's analog input (A0 – A5). The analog-to-digital converter (ADC) in the Arduino then converts 0-5v into digital values (1-1023) using 10-bit resolutions [10]. Barroso *et al.* [11] proposed an average of 0.6 as the factor of multiplication to derive TDS from EC. So the derived TDS can be divided by this factor to get EC.



Fig. 1 A Gravity Analog TDS
(Electrical Conductivity) Sensor [14]

1.2 Turbidity. The word turbidity comes from the Greek word turbid, which means cloudy, hazy, or not pure due to dispersed suspended solids such as silt, clay, algae, organic/inorganic matter or microorganisms [12]. The sensor (Fig. 2) outputs an analog voltage which decreases as turbidity increases. Some modules have a built-in operational amplifier to stabilize the signal. Just like the TDS, the analog signal (0-4.5v) is sent to an Arduino analog pin where the analog-to-digital converter (ADC) converts it into digital values (0-1023) mapped to nephelometric turbidity units (NTU) using calibration details [13].

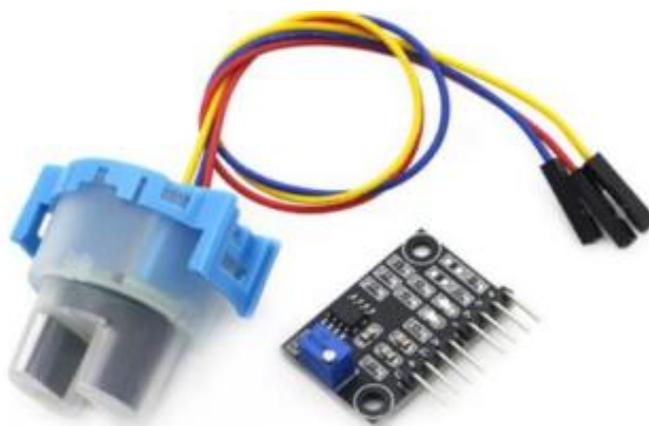


Fig. 2 The Analog Turbidity Sensor [14]

1.3 Arduino Uno. Arduino microcontroller is an open-source that can be easily programmed and can update at any time (Figure 3), it uses hardware known as the Arduino development board and a software known as Integrated Development Environment (IDE) for developing the code [15]. It is built up with the 8-bit Atmel AVR microcontrollers that are manufactured by Atmel or a 32-bit Atmel ARM,

these microcontrollers can be programmed easily using the C or C++ language in the Arduino IDE [16]. The USB cable is used upload the code to the Arduino board. The microcontroller circuit used is the Arduino Uno R3 circuit board based on the AVR ATmega 328P chip [17]. It has 14 digital input/output pins (of which 6 pins can be used as PWM outputs), 6 analog input pins, using a 16MHz crystal, a USB connection, a power jack, an ICSP header and a reset button [9].



Fig. 3 Arduino board and connecting cable.

In the programming of the Arduino board, the Arduino Integrated Development Environment (IDE) is used, and the programs written are called sketches. There are two main functions every Arduino sketch will have: void setup () and void loop () [18-20]. The void setup is the first process that begins when the Arduino starts functioning and it is executed only once throughout the entire program's functioning. The void loop sketch runs infinitely and would never stop once you write the code in it [16].

2. Methodology

2.1 Descriptive Framework

This project focuses on the construction of a low-cost, portable instrument to measure total dissolved solids (TDS), electrical conductivity (EC) and turbidity in water using an Arduino Uno microcontroller. By integrating a TDS sensor and an optical turbidity sensor with the Arduino platform, the system can measure and display parameters in real-time. The instrument is intended to provide accurate, field-ready readings comparable to standard laboratory equipment, offering an affordable solution for environmental monitoring, research and educational purposes. Arduino programming is used to calibrate and display data, making the device user-friendly.

2.2 Data Acquisition and LCD Connection to Arduino Board

The Arduino Uno microcontroller was used to collect and process all data from the sensors, which were in turn displayed on the 16 × 2 LCD display and recorded. The serial monitor on the Arduino IDE was also used to monitor the sensor readings and collect data in situations where the LCD display

malfunctioned. The LCD display was connected to the Arduino Uno board using several jumper cables where necessary. The summary of port to port connections are summarized in Table 1.

Table 1
Connection of LCD display to Arduino Uno board

LCD PIN	ARDUINO UNO PORT
VSS	GND
VDD	5V
V ₀	GND
RS	D ₁₂
RW	GND
EN	D ₁₁
D ₄	D ₅
D ₅	D ₄
D ₆	D ₃
D ₇	D ₂
A (LED +)	5V
K (LED -)	GND

The Turbidity sensor was connected to the Arduino Uno board using jumper cables as well. The VCC pin represented as “+” on the sensor was connected to the 5V port on the Arduino board, the GND pin represented as “-” was connected to the Arduino GND port and the A₀ pin represented as “A” was connected to the Arduino A₀ port. For the TDS sensor, the VCC pin was connected to the Arduino 5V port, the GND pin was connected to the Arduino GND and the A₀ pin was connected to the Arduino A₁ port. The connection is also represented in the sketch on the Arduino IDE in order to identify and read the sensors correctly.

2.3 Power Supply

A power bank (rechargeable battery) will be used to power the instrument for every measurement. The instrument can also be powered by the USB port especially when uploading the sketches for measurement and calibration.

2.4 Instrument Enclosure and Mounting

A plastic container was used to house the microcontroller and sensitive parts of the instrument to ensure it is water proof and durable.

2.5 Calibration and Testing

The sensors were calibrated using the appropriate sketch uploaded to Arduino IDE and the serial monitor interface was opened to monitor readings. The serial monitor baud was set to 9600 baud which is peculiar to the Arduino board and LCD type. The turbidity sensor was dipped in the first standard solution and noted. It was also dipped into the second standard solution. The same for TDS, after which the slope and intercept were derived and printed on the screen from the Arduino IDE. These values were inputted in the measurement sketch and uploaded for continuous measurement by the instrument.

After calibration, the instrument was tested by reading the standard solutions to ascertain the error or accuracy.

In order to calibrate turbidity, standards of smaller values were prepared by volumetric dilution of 4000NTU stock standards. This was achieved by dissolving 1g of hydrazine sulfate in a 100mL distilled water, also dissolve 10g of hexamethylenetetramine in 100mL distilled water. Then 5mL each of both solution was mixed in a 100mL volumetric flask and diluted to the mark with distilled water. This was left for 24 hours at room temperature. The resulting suspension, a 4000NTU turbidity stock solution was diluted to give 400NTU and 40NTU. To get 400NTU, 10mL of stock solution was diluted in a 100mL volumetric flask to the mark with distilled water, while to get a 40NTU, 1mL of the stock solution was diluted in a 100mL volumetric flask to the mark. Figure 4 shows the weighing balance and other components used.



Fig. 4. Weighing balance, 10mL flask, spatula and reagents for experiment (Pure NaCl, Hydrazine sulfate and Hexamethylenetetramine)

To get the TDS standard, 1g of pure NaCl was dissolved in 1 Litre distilled water. The resulting solution would give 1000ppm measurement. To get 500ppm standard, 0.5g was diluted in 1 litre distilled water. These standards were used to calibrate the instrument, and records were taken.

A linear mathematical equation was used to represent the intercept and slope of both sensors as follows

$$y = mx + C \quad (1)$$

Where y = measured or predicted value
 x = sensor output
 m = slope
 c = intercept

3. Results

The sensors were connected appropriately to the Arduino microcontroller using jumper cables where necessary as shown in figure 5.

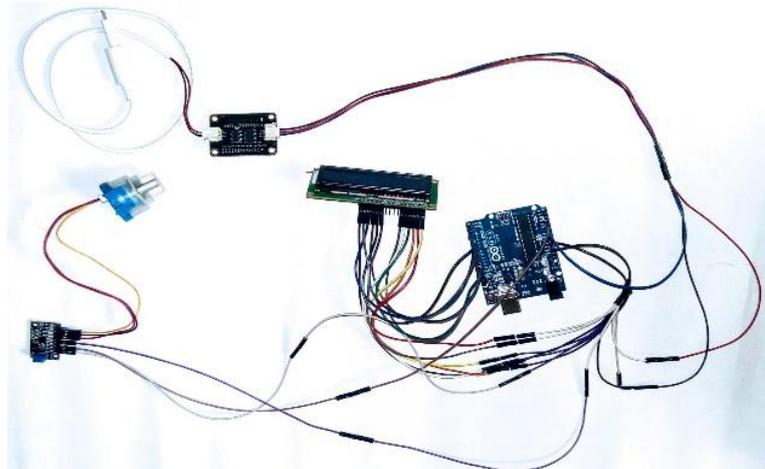


Fig. 5. Complete connection of Arduino Uno board, 16 × 2 LCD display, TDS sensor and Turbidity sensor

The 16 × 2 LCD display was connected to the Arduino Uno board, then the sensors were also connected appropriately. After all connections, the instrument was powered by the laptop as shown in figure 6, ready to be programmed.

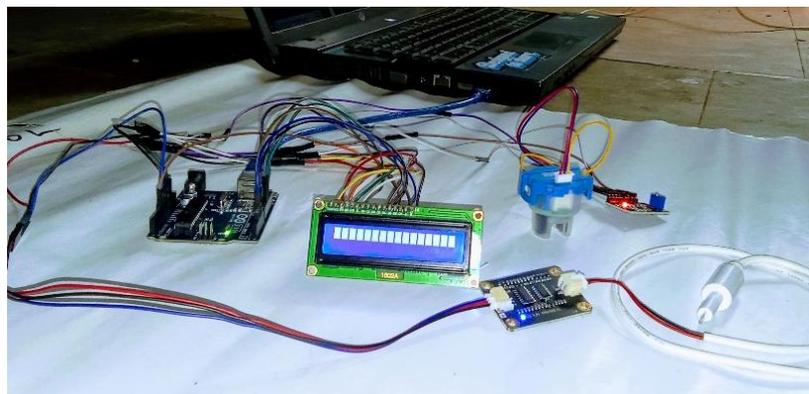


Fig. 6. Complete connection just before uploading sketch to the Arduino Uno board

The LCD display had a blank character indicating that there has not been any code uploaded into the microcontroller through the Arduino IDE. All the lights of the board and those of the sensors blinked continuously to indicate their functionality.

Figure 7 shows the resulting solutions of 1g hydrazine sulfate in 100mL of distilled water and 10g hexamethylenetetramine in 100mL distilled water. The solutions appeared clear and just like the distilled water with particles totally dissolved and bubbles evaporated.



Fig. 7. Formazin Suspension immediately after mixing

After mixing 5mL of each solution in a 100mL volumetric flask and diluting to the mark, the solution still appeared very clear before keeping for. The standard formazin solution started to become cloudy at about 5hours after mixture and Figure 8 shows the solution after 24 hours of storage. This was used as the 4000NTU stock solution for turbidity sensor calibration.



Fig. 8. Formazin suspension
 24hrs after mixing (note the cloudiness)

Having prepared the standard solutions for calibration, the instrument was connected to the computer, and using the Arduino Integrated Development Environment (Arduino IDE) the calibration code was uploaded and the instrument was calibrated using the prompts. After calibration, the results in table 2 were obtained which was used in the codes for measurement.

Table 2
 Calibration Slopes and Intercepts for TDS and Turbidity sensors

Turbidity Slope	Turbidity Intercept	TDS Slope	TDS Intercept
-0.727273	471.3	601.764648	-376.470458

The above values can be represented in the equations below;

$$TDS (ppm) = 601.764648 x - 376.470458 \tag{2}$$

$$Turbidity (NTU) = -0.727273x + 471.3 \tag{3}$$

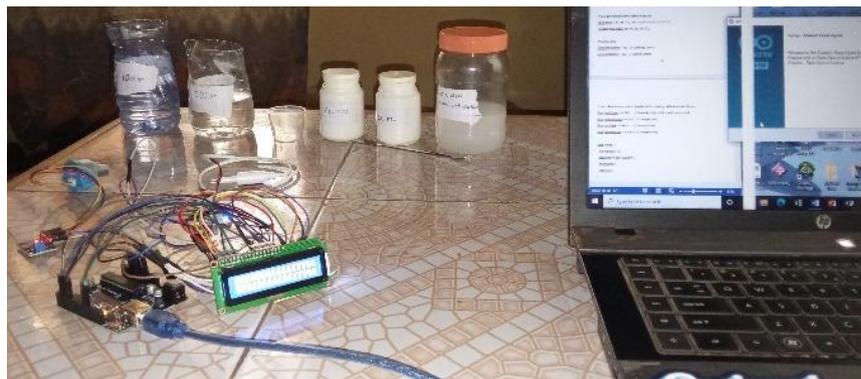


Fig. 9. Calibration of Sensors using different measurements of Formazin suspension and NaCl.

The standards used for turbidity calibration were 400NTU and 40NTU, while for TDS 500ppm and 1000ppm standards were used.

Table 3 shows the measurements after calibration. The deviations were indicative of the imperfection of the sensors and environmental factors like temperature and lighting which can affect the sensors performance.

Table 3
 Measured values vs standard values

	Average Measured Value	Standard value	Percentage Error
TDS	1009ppm	1000ppm	0.9%

	502ppm	500ppm	0.4%
Turbidity	450NTU	400NTU	12.5%
	42NTU	40NTU	5%

4. Conclusions

The results show high percentage error for both sensors. This can be adjusted by continuous recalibration till the error reduces to permissible standards. When the Arduino board and sensors were connected to the computer, they had their various led lights blink to show their functionality. Whenever data was being uploaded into the Arduino board, the light on the board also blinked to indicate the uploading process, then became steady when it was ready for use. It is important to note that the intercepts and slopes were derived from basic mathematical formulas only that they were imputed in the sketch uploaded in the Arduino IDE, so instead of traditionally plotting a graph and looking for slope and intercepts, the computer derived these values from the standard solutions and printed on the serial monitor.

During the production of the formazin turbidity stock standard, the volumetric flask was left open while the other container was closed with a lid. After 24 hours, it was discovered that the volumetric flask had precipitates settled at the base and an almost clear solution. The container with a closed lid on the other hand maintained its cloudy form. The precipitates however were quickly dissolved on stirring and mixed perfectly again to form the cloudy solution as seen in Figure 4.8. Research showed that hydrazine sulfate is very dangerous and carcinogenic if inhaled or even touches the skin, so proper protective wears were used. Gloves, fume masks, protective goggles and a proper overall were used during the preparation. It was also ensured that none of the solutions was inhaled. Initially, the TDS sensor was reading negative values when pulled out of the solution, after calibration. This was quickly corrected by a command added to the code to read all TDS values less than zero as zero. This is encountered most times after calibration as the TDS probe when in air or dry may give unstable or negative values after the conversion.

The turbidity sensor was also discovered to read values inversely. That is higher turbidity read lower values while lower turbidity read higher values. This is usually the case with some turbidity sensors. It was corrected by adding a code in the sketch to invert the reading. So the turbidity ADC value was subtracted from 1023 before calculating with slope and intercept to get the actual value.

It is recommended that in subsequent projects, let sensors of higher sensitivity be procured. They would most likely give better calibration results and measurement output, reducing error drastically and thereby improving performance of instrument. Some other sensors can be integrated into the Arduino board, like pH and temperature. This makes the instrument broader in scope of operations. It is also recommended to use a 10V potentiometer to adjust the contrast of the LCD display, and reconnect a 220 ohms resistor to the "A" pin on the screen. This helps regulate the charge going into the LCD display screen to avoid getting damaged. It is also advised to purchase ready-made formazin stock solution for the calibration of turbidity sensors instead of going through the dangerous process of working with hydrazine sulfate which is carcinogenic.

Author Contributions

Supervision, Ani Ozoemena and Gloria Ezenne. "All authors have read and agreed to the published version of the manuscript."

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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