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Development and Applications of a Liquid Conductivity Tester

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Abstract

The measurement of liquid conductivity plays a pivotal role in numerous industrial processes and scientific applications where the precise monitoring of electrical conductivity in liquids is critical for ensuring product quality, process efficiency, and regulatory compliance. The need to know how much different water samples (sachet water, well water and salty water) conduct electric current led to the development of this instrument. The project focuses on specific aspects to ensure a well-defined and achievable outcome; it entails the use of an Arduino Board microcontroller (ATMEGA328) in place of a micro-controller and other basic electronic components such as 10k resistor, power source, copper clip as well as conductivity sensor. This project takes advantage of the ability of an Arduino board to take input from an external source and perform operations on it based on the program uploaded on the Arduino. The designed meter gives accurate measurements that can be used for industrial purposes. This conductivity tester aims to address needed demands for accurate and cheaper means of measuring electrical conductivity of liquids in various industries and homes. The meter is designed with the use of advanced conductivity probe or sensor with an Arduino Nano board for accurate and timely measurement. An Arduino code programme was used for the measured values to avoid variations in sample conductivity and accuracy when compared with standard values. Measurements carried out with this meter was compared with calibrated standard values and the results shows good correlation coefficients ranging from 0.98 to 0.99. This device is user friendly, and cheaper both in design, maintenance and accurate precision for use in industries.

1.0. Introduction

The accurate measurement of the electrical conductivity of low conducting liquids is an important issue in many industrial applications. The lack of repeatability is a common problem to the available procedures and commercial techniques. In this work, we present a device to measure the electrical conductivity of low conducting liquids taking advantage of their electrolytic properties due to impurities. Deviations in conductivity levels can signify variations in chemical composition, impurity concentrations, or the effectiveness of a treatment process. This device is a cheaper and easy to maintain giving accurate measurements when properly calibrated.

The existing methods for measuring liquid conductivity often face challenges related to simplicity, responsiveness, and adaptability to diverse industrial environments [1], traditional meters may lack the necessary precision required for contemporary industrial applications, and their responsiveness to rapid changes in conductivity can be limited. Additionally, the need for real-time monitoring and control in modern industrial settings necessitates the development of simple, user-friendly, upgradable and reliable liquid conductivity measurement systems.

The motivation behind this project stems from the identified shortcomings in current liquid conductivity meters and the growing demand for a more simple and accessible solution. By leveraging advancements in microcontroller technologies and applications, there is an opportunity to design and construct a liquid conductivity meter that not only addresses the limitations of existing systems but also introduces new capabilities for enhanced accuracy, real-time data acquisition, modification and ease of use [2].

Moreover, the increasing emphasis on sustainable and efficient industrial processes emphasizes the importance of precise conductivity measurements. By accurately assessing and controlling conductivity, industries can optimize chemical processes, reduce waste, and comply with environmental standards [3].

1.1. Real-Time Monitoring: Industries require real-time monitoring capabilities to promptly respond to changes in conductivity. Traditional meters may lack the responsiveness needed to address dynamic industrial processes efficiently [4].

The primary objectives of this work are to design and construct a simple, yet reliable liquid conductivity meter tailored for practical use in various industrial applications [4]. The project aims to address specific challenges associated with existing methods and provide an accessible solution that meets the needs of industries seeking efficient conductivity measurement tools. Other objectives include:

1.2. Adaptability To Different Liquids: Design a system that can effectively measure conductivity across a spectrum of liquid compositions encountered in industrial processes. The goal is to ensure the meter's versatility without compromising the accuracy of measurements [5].

1.3. Cost-Effective Solution: Create a cost-effective liquid conductivity meter that addresses the budget constraints of smaller industries. This objective involves optimizing the design for affordability without compromising the reliability and accuracy of the measurements.

1.4. Real-Time Monitoring Capability: Implement real-time monitoring features to enable prompt responses to changes in conductivity levels. The objective is to enhance the responsiveness of the meter, ensuring its suitability for dynamic industrial processes [6].

The project focuses on specific aspects to ensure a well-defined and achievable outcome; it entails the use of an Arduino Board microcontroller (ATMEGA328) [7] in place of a micro-controller for the project and other basic electronic components such as 10 k resistor, power source, copper clip as conductivity sensor and a vero board, etc. This project takes advantage of the ability of an Arduino board to take input from an external source and perform operations on it based on the program uploaded on the Arduino. we are aware that Temperature affects the conductivity of a Liquid, but This project does not consider the temperature of the Liquid or environment; it assumes all measurements are to be carried out in room temperature (298K or 25°C) but this is subject to change as this project gives room for instrument performance enhancement or upgrade.

The development of a user-friendly interface holds practical significance as it can streamline the operation of the liquid conductivity meter. Simplified calibration procedures and intuitive displays contribute to ease of use, hence reducing the likelihood of errors and enabling a broader range of users to utilize the technology effectively [8]. The significance of this study lies in its potential to help in liquid conductivity measurement in industrial settings and households, fostering greater control, adaptability, and efficiency [9].

1.5. Conductivity in Liquids

Conductivity in liquids arises from the presence of ions—charged particles—within the solution. These ions can be positively charged (cations) or negatively charged (anions), and their movement in response to an electric field contributes to the overall conductivity of the liquid. The concentration and mobility of these ions determine the conductivity level, with higher ion concentrations and greater ion mobility resulting in increased conductivity [6]. A conductivity meter measures the amount of electric current or conductance in a solution. Conductivity is useful in determining the overall of a natural water body. Conductivity meters are common in any water treatment or monitoring situation as well as in environment laboratories

In practical terms, liquids with higher conductivity levels are more effective at conducting electric current. The conductivity of a liquid is influenced by factors such as temperature, the type and concentration of ions present, and the purity of the liquid. Consequently, conductivity measurements provide valuable insights into the composition and properties of the liquid [4].

1.6. Conductivity Probe Meters

These meters utilize a probe with electrodes to measure the conductivity of a liquid. The probe is immersed in the liquid, and the electrical conductivity is determined by the interaction between the liquid and the electrodes. It can be used in laboratories and industrial settings for routine conductivity measurements.

1.7. Microcontroller Applications in Liquid Conductivity Meter Design

In the specific context of this design, the role of microcontrollers - the Arduino nano (ATmega328), is pivotal. The ATmega328 serves as the central intelligence, orchestrating various functions crucial to the meter's performance [8]. In the realm of process control, the Arduino Nano microcontroller-ATmega328 enables real-time adjustments to conductivity measurements. It processes inputs from conductivity sensors or probes and executes control algorithms to maintain optimal conditions and results. This is fundamental to achieving precise and responsive conductivity readings [7].

The Arduino Nano also plays a key role in data acquisition and monitoring. Interfacing with conductivity sensors, it collects, processes, and transmits real-time data, displaying the result in The LCD screen provided in Figure 2. This capability enhances the visibility of conductivity levels, providing essential information for operators and contributing to the reliability of the meter [8].

As an integral part of the user interface development, the Arduino Nano processes inputs from operators and facilitates the display of relevant information. Through intuitive displays, it enhances the user experience, making calibration adjustments and operation more accessible.

Given the Arduino Nano's prowess in communication protocols, it facilitates seamless connectivity within the liquid conductivity meter, this microcontroller supports data exchange, ensuring interoperability among various components, including sensors and the user interface [10]. The Arduino Nano, as the chosen microcontroller, is a central component in the design and functionality of the liquid conductivity meter. Its customizability, versatility, real-time processing power, and compatibility with sensors contribute to the precision, responsiveness, and overall performance of the meter in diverse industries.

2.0. Methodology

2.1. System Design and Overall Architecture

The overall architecture of the liquid conductivity tester revolves around a well-structured integration of components, with the Arduino Nano serving as the central controller. The primary components include two conductivity probes acting as sensors, a power source (9V DC cell, 5 V USB source or a 12 V AC adapter) a 10 kΩ resistor, connectivity wires. The conductivity probes are connected to the Arduino nano-ATmega328, which acts as the brain of the meter. The Arduino processes the analog readings from the probes in voltage, which converts them to micro Siemens taking advantage of the calibration factor derived from our test, and subsequently displays the results on an LCD screen.

2.2. Sensor Selection and Integration

The heart of the system lies in the choice and integration of the conductivity probes as sensors. These probes play a critical role in measuring the resistance generated by the liquid, indicative of its ionic components [9]. The Arduino Nano interfaces with these probes to measure the analog readings, providing insights into the conductivity of the liquid. The selection of appropriate sensors is crucial for achieving precision, responsiveness, and adaptability in diverse industrial liquid compositions.

2.3. Microcontroller Choice (ATmega328)

The ATmega328 is the chosen microcontroller, serving as the central processing unit for the liquid conductivity tester. With its versatility, ease of use, and compatibility with a variety of sensors, the Arduino Nano is well-suited for the real-time processing demands of conductivity measurements.

2.4. User Interface Design - Lcd Display

The user interface is realized through an LCD screen (16 by 2''), providing a clear and concise display of the conductivity results. The LCD screen facilitates user interaction by presenting real-time readings. The Arduino Nano processes the sensor readings and converts them to voltage values, using the Arduino standard of converting analog signals to digital signals in volts, which are then presented on the LCD display. This user-friendly design ensures that operators can easily monitor the conductivity levels of the measured liquid.

2.5. User Interface Testing

User interface testing is a pivotal phase in the evaluation of the liquid conductivity meter, ensuring that the interaction between the system and its operators is intuitive, efficient, and error-free [11]. This testing phase focuses on validating the functionality and responsiveness of the user interface components, which in this case is the LCD display.

2.6. Testing Procedures

Calibration Adjustment Testing

Evaluate the user interface's capability to facilitate easy calibration adjustments. Test the system by adjusting calibration values and observe how the changes reflect in the displayed temperature and conductivity readings.

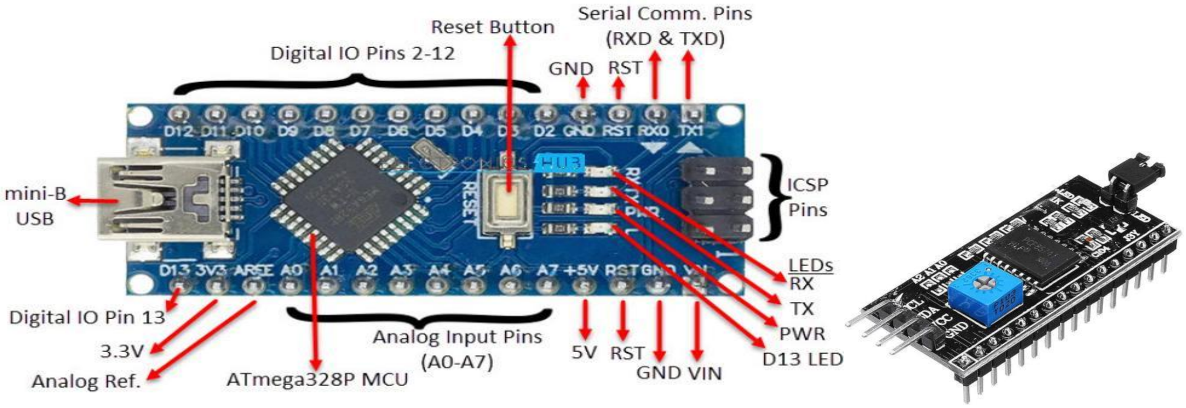
2.7. LCD Display Accuracy

Confirm that the LCD display accurately reflects real-time temperature and conductivity readings. Conduct tests to simulate various operating conditions and ensure the display remains clear, readable, and free from errors.

Intentionally introduce errors, such as incorrect calibration values or out-of-range inputs and assess how the user interface handles these situations. Verify that the system provides clear feedback and error messages for effective troubleshooting.

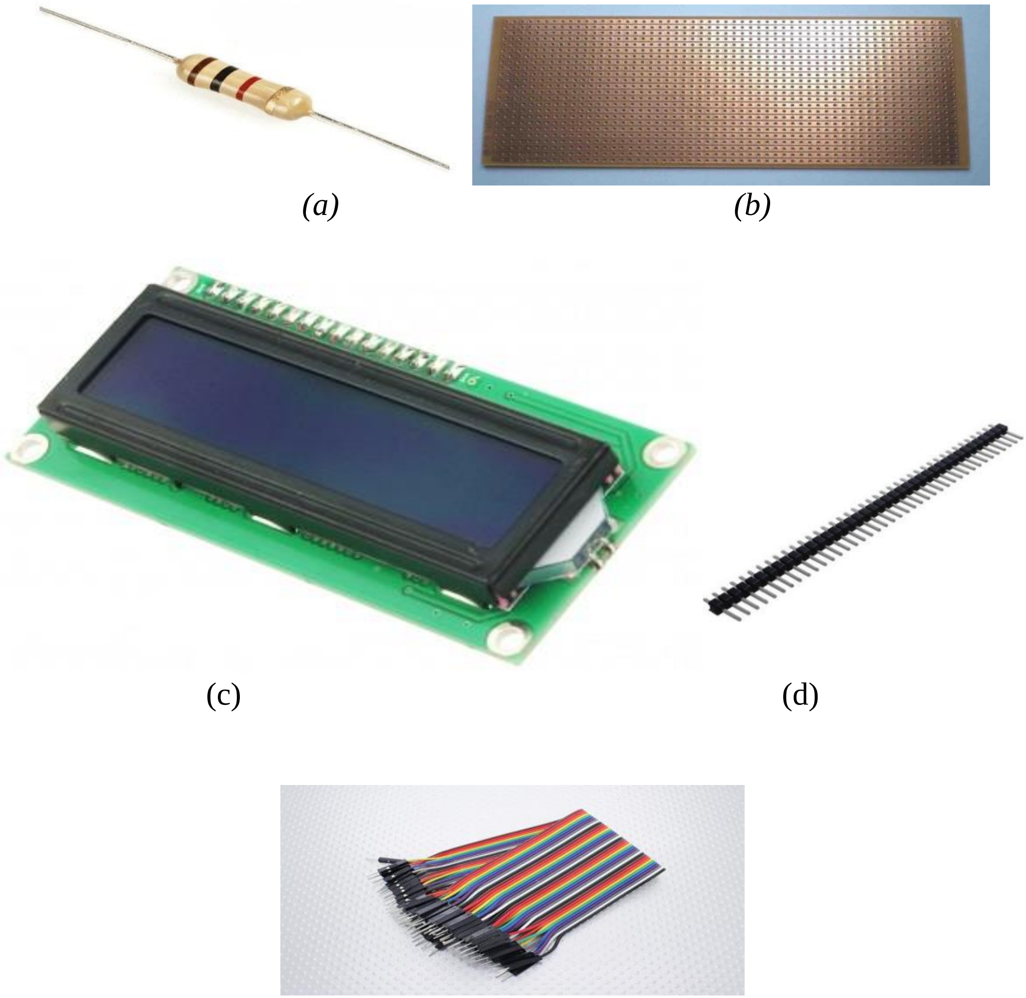
2.2. Materials and components used

1. Arduino Nano board
2. LCD screen (16x2’’)
3. Inter-Integrated Circuit (12C) connection protocol
4. Conductivity probe (sensor)
5. 10k ohm resistor
6. 9V battery or power adapter, or a 5v USB power supply
7. Vero board
8. connecting wires
9. Male headers: to extend the Arduino terminals
10. Soldering iron
11. Soldering led
12. Gum
13. cutter



(a) (b)

Figure 1: (a) Arduino Nano board (b) Inter-Integrated Circuit (12C)



(a) *(b)*

(c) (d)

(e)

Figure 2: (a) ***10k ohm resistor*** **(b)** ***vero board*** **(c)** ***LCD screen (16x2)*** **(d)** ***.Male headers*** **(e)** ***Connecting wires***

Arduino Uno Connection:

1. Connect the 5V pin on the Arduino Uno to the positive rail of the vero board.
2. Connect the GND (ground) pin on the Arduino Uno to the negative rail of the vero board.
3. Connect the A0 pin on the Arduino Uno to the analog output of the conductivity probe.

Conductivity Probe Connection:

4. Connect one end of the first conductivity probe to the positive rail of the vero board.
5. Connect the other end of the first probe to one end of the 10k ohm resistor.
6. Connect the other end of the 10k ohm resistor to the negative rail of the vero board.
7. Connect the free end of the resistor to the A1 pin on the Arduino Uno.

LCD Screen Connection:

8. Connect the VCC (power) pin on the LCD screen to the positive rail of the vero board.

9. Connect the GND (ground) pin on the LCD screen to the negative rail of the vero board.
10. Connect the SDA pin on the LCD screen to the A4 pin on the Arduino Uno.
11. Connect the SCL pin on the LCD screen to the A5 pin on the Arduino Uno.

Temperature Sensor Connection (Optional):

12. Connect the VCC (power) pin on the temperature sensor to the positive rail of the vero board.
13. Connect the GND (ground) pin on the temperature sensor to the negative rail of the vero board.
14. Connect the data pin on the temperature sensor to any available digital pin on the Arduino Uno (e.g., D2).

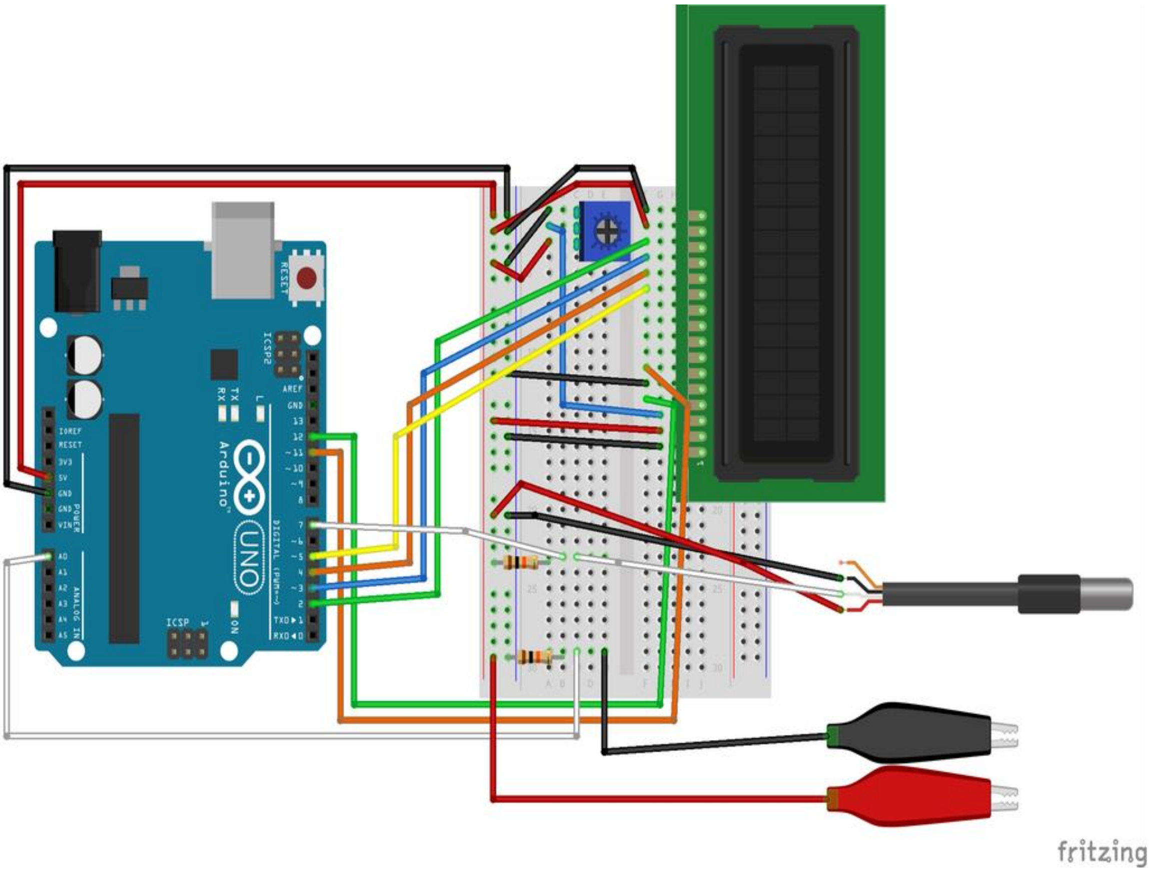


Figure 3: Diagram depicting connection made with fritz app

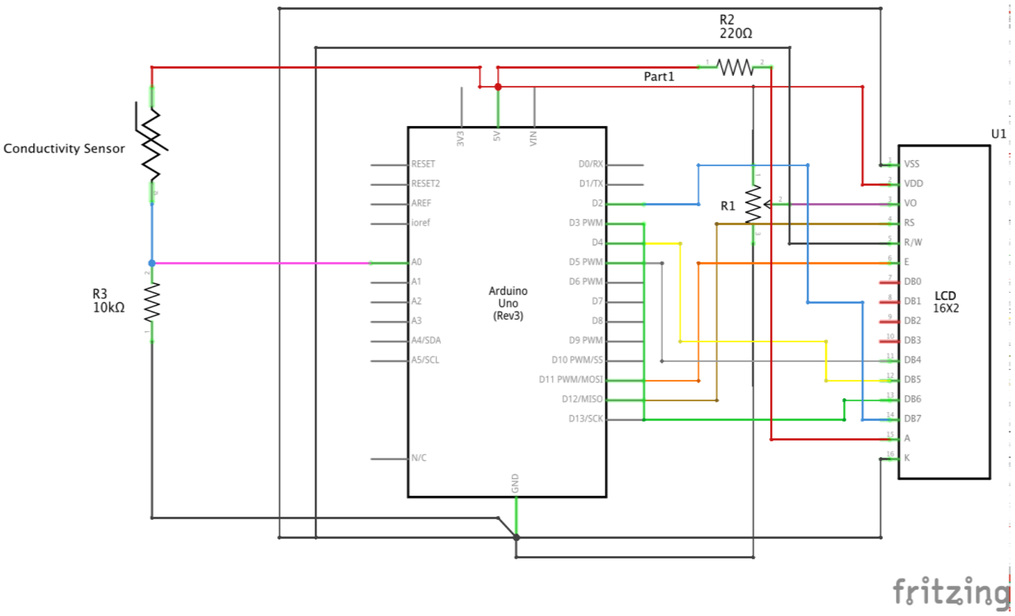


Figure 4: Circuit diagram

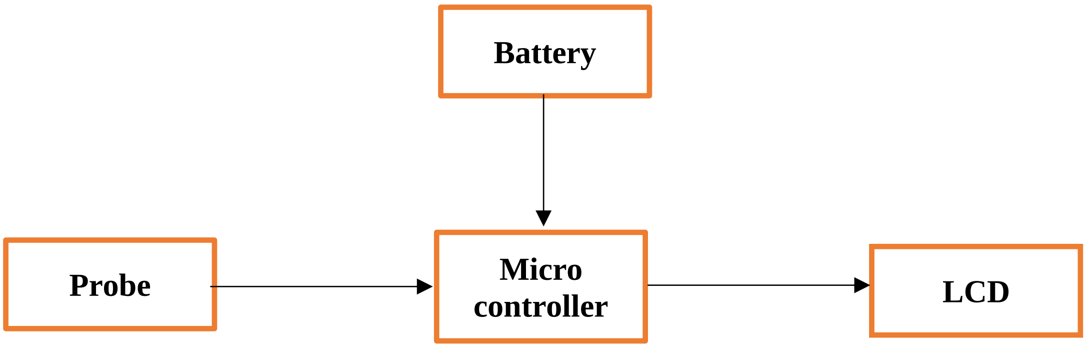


Figure 5: Block Diagram

Figure 6: Conductivity Meter

Figure 3 is the complete set up of the liquid conductivity tester while figure 4 is circuit diagram. Figure 6 is the cased developed conductivity meter that is ready for use.

2.8. Program Code and How It Works

Figure 7 is the Arduino code snippet used. With the necessary libraries for the LCD screen and wiring installed.
The provided Arduino code is designed for the liquid conductivity meter, incorporating temperature and conductivity measurements with calibration factors [5 and 9].

2.8.1. Initialization:

The LCD display is initialized with the specified address and dimensions (16x2).
The liquidCrystal library is initialized for communication with the i2C.

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

const float ArduinoVoltage = 5.00;
const float ArduinoResolution = ArduinoVoltage / 1024;
const float resistorValue = 10000.0;
int threshold = 3;
int inputPin = A0;
int ouputPin = A5;

const double conductivityFactor = 2.002333; // average conductivityFactor value to multiply

LiquidCrystal_I2C lcd(0x27, 16, 2);

void setup() {
  lcd.begin(16, 2);
  lcd.backlight();
  lcd.print("Water Cond Meter.");
  lcd.setCursor(0, 1);
  lcd.print("Taiwo Emmnauel");
  delay(2000);

  pinMode(ouputPin, OUTPUT);
  pinMode(inputPin, INPUT);
}

void loop() {
  int analogValue = analogRead(A0);
  int oldAnalogValue = 1000;
  float returnVoltage = 0.0;
  float resistance = 0.0;
  double Siemens = 0.0:
```

```
void loop() {
  int analogValue = analogRead(A0);
  int oldAnalogValue = 1000;
  float returnVoltage = 0.0;
  float resistance = 0.0;
  double Siemens = 0.0;
  double MicroSiemens = 0.0;
  double conductivityValue = 0.0;

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Voltage: ");

  returnVoltage = analogValue * ArduinoResolution;
  lcd.print(returnVoltage, 2); // Display voltage with 2 decimal places

  lcd.setCursor(0, 1);
  lcd.print("Cndtanc: ");
  resistance = ((5.00 * resistorValue) / returnVoltage) - resistorValue;
  Siemens = 1.0 / (resistance);
  MicroSiemens = Siemens * 1000000 * 1.669; // Convert Siemens to Microsiemens
  conductivityValue = MicroSiemens * conductivityFactor; // Multiply by conductivity factor
  lcd.print(conductivityValue, 4); // Display conductivity value with 4 decimal places


  delay(2500);
}

```

Figure 7: Arduino code

.

2.8.2. Setup Function:

The setup function initializes the LCD.

2.8.3. Loop Function:

Reads the conductivity from the analog pin connected to the conductivity probe.

Converts the analog reading to voltage and then to conductivity, applying the logic illustrated in the code.
Displays the conductivity values on the LCD screen.
Delays for 1000 milliseconds (1 second) before the next iteration.

2.8.4. Display:

The LCD display shows real-time conductivity readings in microsiemens per centimeter (µS/cm).

2.8.5. Continuous Operation:

The loop continuously executes, providing a continuous display of conductivity readings on the LCD screen.
In summary, the system design incorporates the Arduino Nano microprocessor (ATmega328) as the central controller, conductivity probes as sensors, and an LCD display for user interaction. The chosen components and materials form a cohesive system architecture, ensuring the accurate and reliable measurement of liquid conductivity in industrial applications.

2.9. Evaluation Criteria

2.9.1. Clarity and Readability:

Assess the clarity and readability of information presented on the LCD display. This ensures that operators can easily interpret temperature and conductivity readings without ambiguity.

2.9.2 Consistency Across Functions:

This verifies that the user interface maintains consistency in its design and operation across different functions. Consistency contributes to a seamless user experience and reduces the likelihood of errors.

2.9.3. Documentation Of Calibration Parameters

Calibration is a crucial step to ensure accurate and reliable measurements of temperature and conductivity. This section provides a comprehensive guide on the calibration parameters used in the liquid conductivity meter. The parameters documented here include voltage to conductivity factors (VCF) derived from the calibration process.
This documentation serves as a reference for users, providing insights into the calibration parameters used to achieve accurate temperature and conductivity measurements in various sample liquids.

2.9.4. Conductivity Calibration

Conductivity calibration is a critical process within the development and maintenance of a liquid conductivity meter [12]. This calibration ensures that the readings obtained from the conductivity probes accurately reflect the actual conductivity levels of the measured liquid. Conductivity calibration is particularly important due to the variability in liquid compositions encountered in industrial processes.

2.9.5 Calibration Procedure:

i. ***Preparation of Standard Solutions:***

Begin by preparing a series of standard solutions with known conductivity levels. These solutions cover a range of conductivity values that may be encountered in practical industrial scenarios.

ii. ***Immersion of Conductivity Probes:***

Immerse the conductivity probes into each standard solution, allowing the probes to interact with the liquids. Ensure that the probes are submerged fully and consistently for accurate readings.

iii. ***Recording Readings:***

Record the readings obtained from the conductivity probes for each standard solution. These readings serve as reference points for calibrating the system to known conductivity levels.

iv. **Adjusting The Code's Conversion Factor:**

Analyze the disparities between the recorded readings and the actual conductivity values of the standard solutions. Adjust the conversion factor in the code to align the sensor's output with the true conductivity levels.

3.0. Results

3.1 Conductivity Calibration Results

Three water samples (sachet water, well water and salt water) and petrol liquid samples were tested with the designed equipment and the results are as shown below.

3.1.1. Sample Liquid: Sachet Water (Easy Fill)

Measured Conductivity (MC): 17 µS/cm
Known Conductivity (KC): 28 µS/cm
Calibration Factors (CF): KC/MC=28/17 ≈ 1.647
Calibrated Conductivity (CC) = Measured Conductivity (MC) X Calibration Factor (CF)
Calibrated Conductivity (CC) = 17 µS/cm * 1.647 ≈ 28.458 µS/cm

3.1.2. Sample Liquid: Well Water

Measured Conductivity (MC): 127 µS/cm
Known Conductivity (KC): 240 µS/cm
Calibration Factors (CF): KC/MC=240/127 ≈ 1.889
Calibrated Conductivity (CC) = Measured Conductivity (MC) X Calibration Factor (CF)
Calibrated Conductivity (CC) = 127 µS/cm * 1.889
≈ 240 µS/cm

3.1.3. Sample Liquid: Salt Water

Measured Conductivity (MC): 259 µS/cm
Known Conductivity (KC): 640 µS/cm
Calibration Factors (CF): KC/MC=640/259 ≈ 2.471
Calibrated Conductivity (CC) = Measured Conductivity (MC) X Calibration Factor (CF)
Calibrated Conductivity (CC) = 259µS/cm * 2.471 ≈ 640µS/cm

3.1.4. Sample Liquid: Petrol

Measured Conductivity (MC): 0µS/cm
Known Conductivity (KC): 2.5 µS/cm
Calibration Factors (CF): KC/MC=2.5/0 ≈ 0
Calibrated Conductivity (CC) = Measured Conductivity (MC) X Calibration Factor (CF)
Calibrated Conductivity (CC) = 0µS/cm * 2.5 ≈ 0µS/cm

The Electrical Conductivity of Gasoline (Petrol) is so low that Gasoline and other similar hydrocarbons such as Kerosene, Jet, Diesel, and fuel oil are considered to be dielectrics (non-conductors or insulators). This is why the value obtained from the meter is 0 V. Since all materials contain a small number of mobile charge carriers (electrons, “holes”, or ions) that will move under the influence of an electric field (an applied voltage), but it now depends on how much a material conducts electricity.

For the given data:

Sachet Water (easy fill):
Calibration Factor (CF1) = 28 / 17 ≈ 1.647

Well Water (first measurement):
Calibration Factor (CF2) = 240 / 127 ≈ 1.889
Well Water (second measurement):
Calibration Factor (CF3) = 640 / 259 ≈ 2.471

Now, let's find the average of these calibration factors:

Average Calibration Factor = (CF1 + CF2 + CF3) / 3

Plugging in the values:
Average Calibration Factor = (1.647 + 1.889 + 2.471) / 3
Average Calibration Factor ≈ 2.002333

So, the average calibration factor is approximately 1.669.

Representing the values obtained in tabular and graphical forms we have:

Table 1: Recording Sample Liquid, Liquid Measured Conductivity (µS/cm), known conductivity (µS/cm) and calibration factor

Sample Liquid	Liquid Measured Conductivity (µS/cm)	Known Conductivity (µS/cm)	Calibration Factor
Sachet Water	17	28	1.647
Well Water	127	240	1.88
Salt Water	259	640	2.471

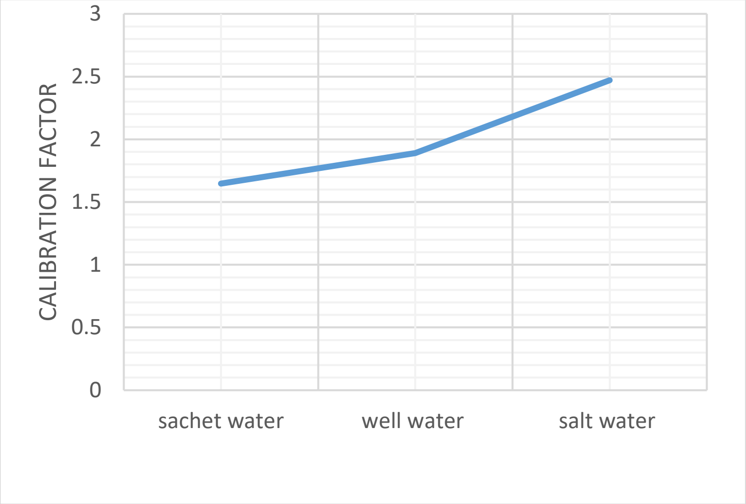


Figure 8: Plot of Calibration Factors for different water Samples

The calibration factor for different categories of water are as shown above in figure 8. Result shows that the conductivity of salt water is higher than that of well water which in turns is also higher than that of sachet water.

Table 2: Salt water volume, Measured Voltage, and Measured conductivity Value

Volume(liters)	Measured voltage(v)	Measured Conductivity(µs/Cm)
0.50	3.69	556.169
0.75	3.57	497.813
1.00	3.48	450.683
1.25	3.40	421.096
1.50	3.35	399.295
1.75	3.25	370.319

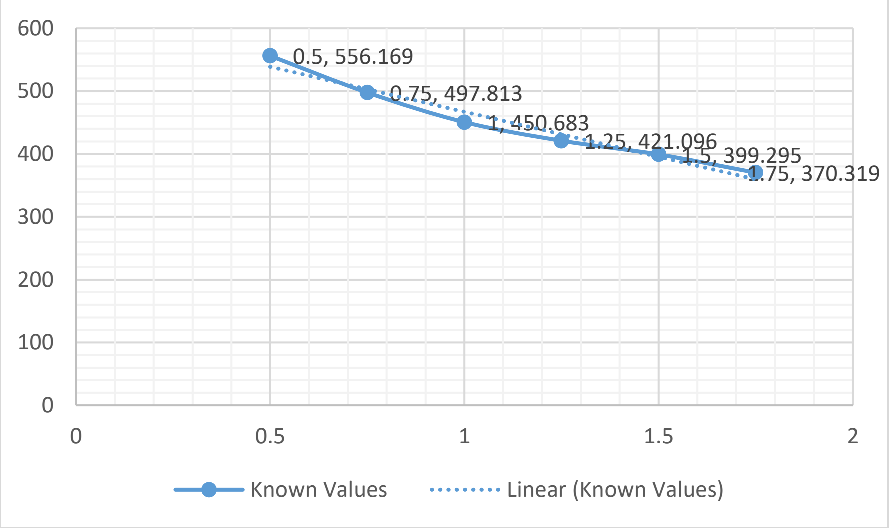


Figure 9: Graph of Know Conductivity Values and Measured Conductivity

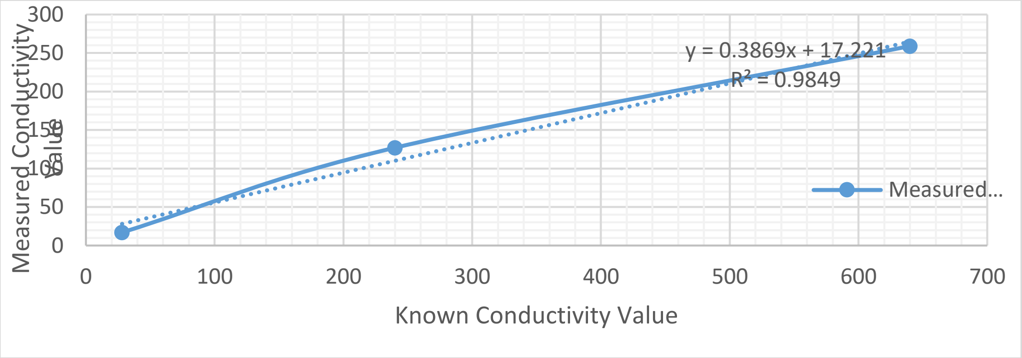


Figure 10: Graph of Known Conductivity Value (x-axis)/ Measured Conductivity Value (y-axis)

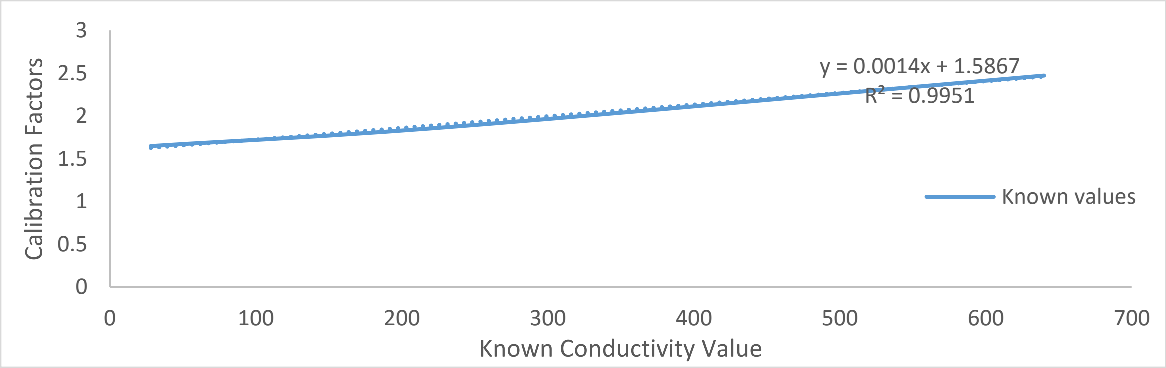


Figure 11: Plot of Known Conductivity Value(x-Axis)/ Calibration Factors(y-Axis)

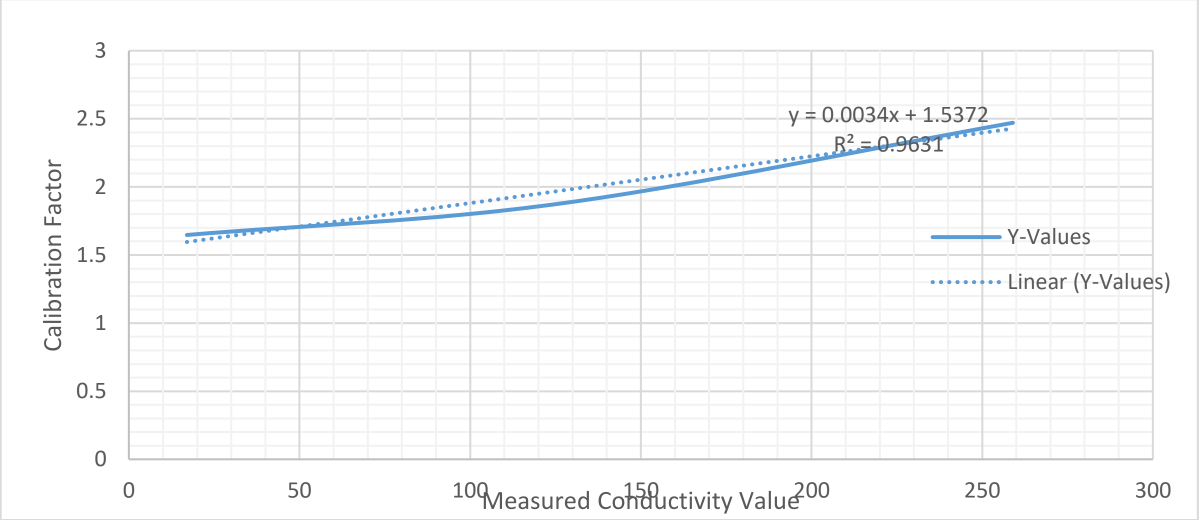


Figure 12: Plot of Calibration factor with Measured conductivity values of Water

Considering different volumes of liquid (water of same source), results in figure 9 shows that the conductivity decreases as the volume increase with the probes maintaining same distance apart. Figures 10, 11, and 12 shows plots of known or standard conductivity values with measured conductivity values with standard calibration factors. The plots show good correlation of 0.98, 0.995 and 0.963 thus confirming the accuracy of the developed equipment.

This calibration procedure be repeated multiple times to get accurate and efficient conductivity factor for a range of test, and on testing it was noted that linear and more accurate result were gotten between the voltage drop of 0 V to 3 V. This tell us that our conductivity meter is more accurate and easily calibrated within this range

4.0. Conclusion

In this research work, the focus was on the design and development of a liquid conductivity meter for industrial applications. It started with an exploration of sensor technologies employed in liquid conductivity measurement covering conductive probe sensors, Toroidal sensors, inductive sensors, and Capacitive sensors. The choice of the ATmega328 as microcontroller which is the central intelligence for the meter was justified, highlighting its role in real-time adjustments, data acquisition, and user interface development.

The overall architecture was presented, emphasizing the integration of key components such as conductivity probes, and an LCD display. Detailed wiring instructions were provided, ensuring the correct connection of components on the stripboard. The Arduino code snippet was explained, elucidating its role in processing temperature and conductivity data, calibration, and displaying results on the LCD screen.

Testing, Calibration, and Validation were thoroughly discussed. The importance of temperature and conductivity calibration was highlighted, outlining step-by-step procedures and the significance of multi-point calibration. System Integration Testing focused on verifying the functionality, responsiveness, and adaptability of the liquid conductivity meter. User Interface Testing assessed the LCD display, calibration adjustments, and user input responsiveness. Calibration parameters were documented to guide users through the re-calibration process.

In conclusion, the liquid conductivity meter developed here represents a significant advancement in industrial instrumentation. Its contributions to precision, adaptability, user-friendliness, and documentation lay the foundation for future innovations in the field. The system's versatility in sensor technologies and the potential for further enhancements open avenues for continuous improvement and exploration in industrial conductivity measurement.

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