ARDUINO BASED CAPACITANCE SENSOR

A SUMMER PROJECT REPORT

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in partial fulfillment for the award of the degree of

BACHELOR OF ENGINEERING

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

DEPARTMENT OF ELECTRONICS ENGINEERING

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ABSTRACT

The project titled “Arduino Based Capacitance Sensor” involves the design and implementation of a capacitance measurement system using Arduino, for liquid analysis applications. The cavity sensor acts as a liquid dielectric holder, and its capacitance is measured to assess material properties. The Arduino microcontroller controls the charging and discharging of the cavity and captures capacitance values in pF , nF and uF ranges. Results are displayed on a 16x2 LCD, offering real-time feedback. The project demonstrates the application of capacitive sensing and Arduino programming for liquid analysis, providing a foundation for further research and innovation in liquid dielectric measurement.

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CHAPTER 1
INTRODUCTION

1.1 Capacitance As A Property of Materials :

Measuring the capacitance of materials, particularly liquids, is crucial in understanding their dielectric properties, which directly relate to their molecular structure and ability to store electrical energy. This information is valuable in various fields, as capacitance data can reveal insights into a liquid's purity, concentration, and even temperature-dependent behaviors. Additionally, capacitance measurements are non-invasive and sensitive, making them an ideal method for monitoring subtle changes in material properties.

Capacitance measurement has extensive applications across industries. In the chemical industry, it is used to analyze the concentration and purity of liquid solutions, which is vital in quality control. In environmental monitoring, capacitance sensors are used to detect moisture levels and the presence of specific contaminants in water. In the food and beverage industry, capacitance measurement helps monitor the composition and quality of liquids, such as oils and alcoholic beverages. These measurements also play a role in medical diagnostics, where they can help characterize biological fluids and detect changes in bodily fluids, supporting various health assessments.

The several techniques for measuring capacitances range from Direct Current (DC) to microwaves. Decision is made based on several parameters commonly landing on devices and instruments such as parallel plate capacitor, coaxial probe, waveguide, resonance structure, and LCR meter.

In this project a cavity is used as a medium to contain the liquid of which the capacitance is the be tested. Using the arduino the conductive plates (Copper) is charged and discharged at predefined intervals hence helping us determine capacitances depending on the material's dielectric constant, distance between the plates, and the area of the plates.

Various liquid samples can be loaded and unloaded in less time. This method is completely repeatable and it shows a better accuracy due to the ease of calibration of arduino. The various capacitance values hence obtained can be used to study the purity and concentration in a non-invasive manner.

1.2 Arduino UNO

1.2.1 Microcontroller Overview

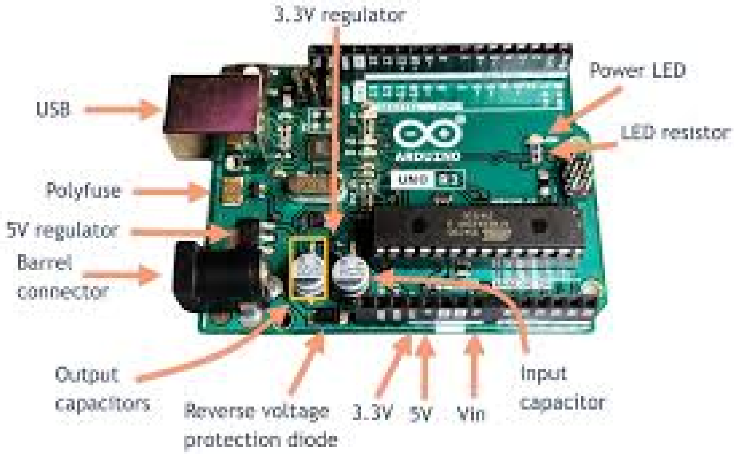


Figure 1.3 Arduino UNO

The Arduino Uno is a popular microcontroller board based on the ATmega328P microcontroller. Widely used for prototyping and educational purposes, it offers a blend of ease of use, versatility, and affordability. The board's design and functionality make it ideal for beginners and experienced developers alike, allowing users to create interactive devices that can sense and control objects in the physical world.

Specifications

1. Microcontroller: ATmega328P (8-bit AVR)
2. Operating Voltage: 5V
3. Input Voltage (recommended): 7-12V
4. Digital I/O Pins: 14 (of which 6 provide PWM output)
5. Analog Input Pins: 6
6. Clock Speed: 16 MHz
7. Flash Memory: 32 KB (0.5 KB used by the bootloader)
8. SRAM: 2 KB
9. EEPROM: 1 KB
10. Communication Protocols: UART, I2C, SPI

The Arduino Uno's USB port allows for easy programming via a computer, and it also provides power when connected via USB. Additionally, the board includes a power jack for external power and a built-in reset button for restarting the microcontroller.

In this project, the Arduino Uno serves as the central processing unit. It's responsible for managing the following key functions:

1.Capacitance Measurement: The Arduino reads the capacitance value across the two plates of the setup. This is done by detecting the charging and discharging cycle of the capacitor formed by the liquid-filled cavity, where different liquids result in varying capacitance values. The Arduino's analog input pins are used to read and interpret these values.

2.Display Output: The Arduino communicates with a 16x2 LCD display to show the capacitance readings in real-time. Using I2C or standard digital pins, the Arduino sends instructions to the LCD, which then displays the capacitance value, allowing users to observe changes based on the liquid in the cavity.

3.Data Processing and Control: The Uno processes the raw data from the capacitor, calculates the effective capacitance, and manages the charging and discharging of the plates. Through control of the charged plates, it creates an effective capacitive sensing mechanism.

4.Interface for Further Expansion: The digital and analog pins on the Arduino Uno allow for potential expansion, meaning more sensors or control elements could be added to enhance the project, such as additional displays, communication modules, or other sensors to measure environmental factors.

1.3 I2C Liquid Crystal Display

1.3.1 I2C and LCD Overview

Figure 1.4 I2C and LCD DISPLAY

The I2C (Inter-Integrated Circuit) LCD display is a convenient display module that uses an I2C communication interface, requiring only two communication lines, which minimizes wiring complexity and conserves the Arduino's input/output pins. Commonly, a 16x2 LCD is used, providing two rows of 16 characters each, making it suitable for projects that need to display real-time data in a simple, compact form.

Specifications

1. Display Type: 16x2 (16 characters per line, 2 lines)
2. Backlight: LED backlight, usually controllable
3. Contrast Adjustment: Adjustable using a potentiometer on the module
4. Communication Interface: I2C protocol, typically using a PCF8574 I2C backpack adapter
5. Voltage: Operates at 5V, compatible with Arduino
6. Pins Used:
    a. SDA (Data): Data line for I2C communication, often connected to Arduino's A4 (on Uno)
    b. SCL (Clock): Clock line for I2C communication, typically connected to A5 (on Uno)
7. I2C Address: Standard address is 0x27 or 0x3F, but it may vary based on the module and can be customized.

The I2C interface, requiring only two connections (SDA and SCL), helps conserve other I/O pins on the Arduino and is ideal for integrating multiple devices. The address of the module enables multiple I2C devices on the same bus.

In this project, the I2C LCD display is used to visually display the capacitance values of various liquids placed between the capacitor plates. Key roles of the display in this setup include:

1.Real-Time Capacitance Display: The display shows the capacitance values measured by the Arduino, allowing users to observe how different liquids affect capacitance. This is particularly useful for confirming real-time data changes as the cavity's liquid content is varied.

2.User Feedback: By displaying results clearly, the I2C LCD helps make the project more user-friendly. Users can easily see the data without needing to connect the Arduino to a computer or use serial monitoring software, making it a self-contained and practical setup.

3.Compact and Efficient Setup: Using the I2C interface reduces the pin count and minimizes the complexity of wiring. This is particularly advantageous in compact setups, leaving more pins available for other components or future expansions.

CHAPTER 2

SIGNIFICANCE OF DIELECTRIC PROPERTIES & CONSTRUCTION

2.1 DIELECTRIC PROPERTIES OF MATERIALS :

For every material there is an unique electrical characteristics that depend on its dielectric properties and the measurement of these properties can provide engineers and scientists with valuable information about the MUT (Material Under Test) to use it with different applications. Dielectric properties of the MUT describe its behaviour when it is exposed to EM waves. These properties encompass dielectric permittivity, dielectric permeability, resistivity and conductivity. Some materials, such as the natural biological materials do not interact with a magnetic field. Thus, their dielectric permeability is the same as the dielectric permeability of the free space. Hence in this work the calculation of only the relative dielectric materials (ε) is done.

2.2 RELATIVE DIELECTRIC PERMITTIVITY :

Relative dielectric permittivity is the dielectric property used to explain interactions of materials with electric fields and it determines the interaction of EM waves with the matter and defines the charge density in an electric field. Relative dielectric permittivity is normally written in a complex number. The real part is the dielectric constant, and the imaginary part is the dielectric loss factor.

Dielectric constant (relative permittivity), (ε) is related to the capacitance of a substance and its ability to store electrical energy when an external electric field is applied. Dielectric constant is also named as relative permittivity or dielectric factor. It is useful to know that the value of this parameter is not constant, although it carries the name dielectric constant and it varies from material to material. Relative permittivity, like other parameters, changes with temperature, humidity, moisture, composition, frequency of the applied field, etc.

2.3 Circuit and Construction :

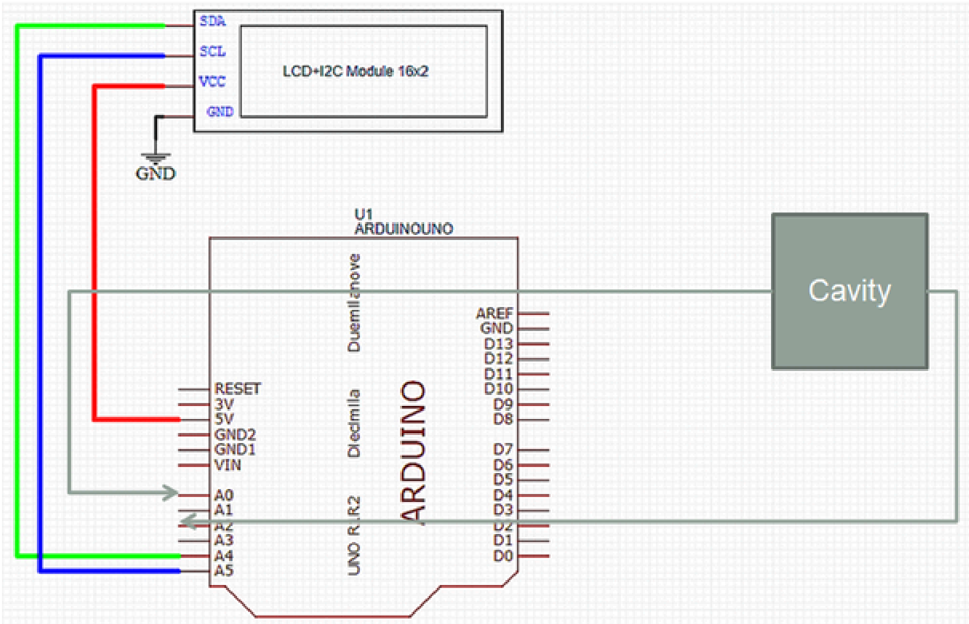


Figure 2.1 Circuit Diagram

Connecting to Arduino Analog Pins:
The wires from the copper plates were connected to the Arduino's analog pins, enabling the Arduino to control and monitor the capacitance across the cavity. This connection completes the setup, as the Arduino now can read changes in capacitance, driven by the dielectric properties of the liquid placed in the cavity.

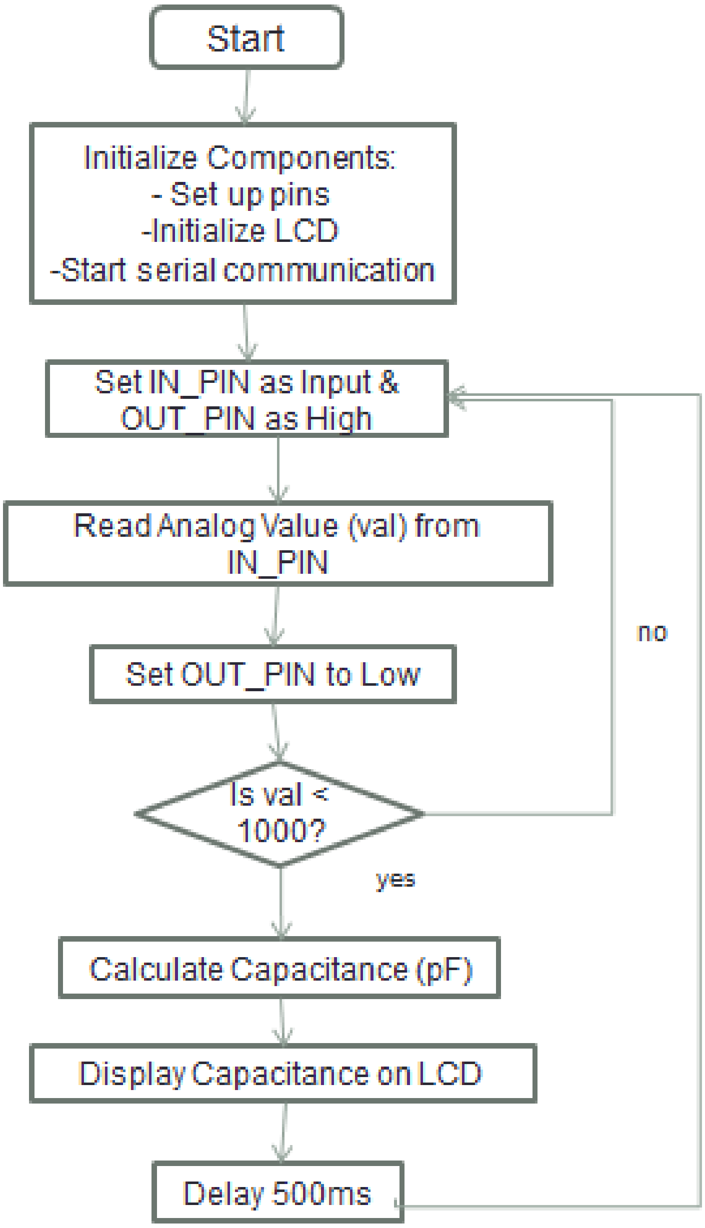
Arduino to LCD I2C Connection:
The SDA , SCL , GND and VCC pins from the I2C ports of LCD are aptly connected to the Arduino ensuring real-time accurate and clear display of capacitance values without delay to the user.

Each step of this construction process contributes to creating a stable, precise, and effective capacitive sensing environment. The accurate assembly and secure electrical connections allow reliable capacitance measurements, ensuring that the setup is both functional and durable for repeated testing.

CHAPTER 3

Measurement of Capacitance from Arduino Based Capacitance Meter

3.1 Source Code for Arduino Based Capacitance Meter :



An overview of the critical components in the code:

Key Libraries and Constants

1.#include <LiquidCrystal_I2C.h>: This library enables communication with an I2C-based LCD, simplifying display control with minimal wiring.

2. Constants:
- IN_PIN and OUT_PIN: Define the analog and digital pins for capacitance measurement.
- IN_CAP_TO_GND: Represents an internal capacitance value, used for calculations.
- R_PULLUP: Defines the pull-up resistor value.
- MAX_ADC_VALUE: The maximum value for the Arduino's 10-bit ADC (1023).
- CALIBRATION: Used to calibrate capacitance readings, ensuring greater accuracy.

3. BAUD_RATE: Sets the serial communication rate to 115200, allowing fast data transfer to the Serial Monitor for debugging or data logging.

Setup Function

The setup() function initializes the required components:
1.pinMode():
Sets OUT_PIN and IN_PIN as output pins. This configuration allows the Arduino to drive and control these pins during the capacitance measurement.

2. LCD Initialization:
The LCD is initialized and configured to start with a backlight and a cursor at position (0,0). The 16x2 display can now be used to show capacitance values.

3. Serial Communication:
Serial.begin(BAUD_RATE) initiates serial communication, which allows capacitance values to be printed to the Serial Monitor for testing and debugging purposes.

Main Loop

The loop() function continuously executes capacitance measurements and updates the display.

1.Setting Input Mode: Setting IN_PIN to INPUT and OUT_PIN to HIGH begins the measurement process by allowing the input pin to sense the charge transferred to it.

2.Capacitance Calculation:
- val = analogRead(IN_PIN): Reads the voltage at the input pin, where val represents the charge across the capacitor plates.
- If the val is less than 1000, the program proceeds to calculate capacitance using the formula:

$$\text{capacitance} = \left| \frac{(\text{val} \cdot \text{IN CAP TO } GND)}{\text{MAX ADC VALUE} - \text{val}} - \text{ CALIBRATION} \right|$$

This equation calculates capacitance in picofarads (pF), adjusting for internal capacitance and calibration to improve measurement accuracy.

3.Condition Check:
The condition if (val < 1000) ensures only valid values are processed, filtering out excessively high readings that could result from noise or environmental factors.

4. Data Output:
   - Serial Output: Prints the capacitance in pF to the Serial Monitor using Serial.print() and Serial.println().
   - LCD Display Update:
     - lcd.clear(): Clears previous readings from the LCD.
     - lcd.setCursor() and lcd.print(): Update the display with the new capacitance value, showing it with units (pF).
   - delay(500): Adds a delay to stabilize readings and update every 0.5 seconds, preventing rapid flickering on the display.

In summary, this code uses capacitance readings from analog input, calculates the effective capacitance value, and displays it on an LCD. The I2C LCD simplifies wiring and display control, while key constants and the calibration variable ensure accuracy in displayed measurements.

3.2 Obtaining Measurements

To obtain accurate capacitance readings for various liquid samples using the capacitive sensing device, a careful sequence of steps should be followed. Each step ensures reliable and consistent results, while preventing interference that could disrupt measurements. Following is the detailed procedure:

1.Powering the Device:
Begin by powering up the device, either by connecting it to a USB power source or using a 9V battery attached to the Arduino. A steady and reliable power source is crucial for maintaining consistent capacitance readings throughout the experiment. USB power provides stable voltage, especially useful for laboratory environments, while a 9V battery is more suitable for portable applications.

2.Baseline Measurement with an Empty Cavity:
Once the device is powered on, observe the capacitance reading on the LCD display when the cavity is empty. This initial reading provides a baseline capacitance value for an air-filled cavity, which can be used for comparison with liquid-filled readings. An empty cavity acts as a control to establish a reference value. This baseline is important because it helps quantify the relative change in capacitance when a liquid is added, thus highlighting the dielectric effect of the liquid sample.

3.Adding the Liquid Sample:
Carefully pour the chosen liquid sample into the cavity until it is fully filled. Ensuring that the cavity is completely filled with the sample is crucial for accurate readings. Any air gaps or incomplete filling can cause inconsistencies in capacitance, as they alter the dielectric medium between the capacitor plates. Additionally, filling the cavity fully enables a uniform electric field across the plates, providing accurate capacitance measurements directly related to the liquid’s dielectric properties.

4.Observing the LCD Display:
After filling the cavity, check the capacitance value displayed on the LCD screen. The display shows the real-time capacitance reading in picofarads (pF), allowing you to observe how the particular liquid affects the capacitance compared to the baseline reading. This step is where the core data for your experiment is gathered. Differences in readings across different liquids reveal how their dielectric constants impact capacitance, providing insights into their material properties.

5.Avoiding External Obstructions:
During the measurement, it’s important to keep the cavity area free from external obstructions, such as physical objects or nearby electrical devices. External factors can influence the capacitance measurement by affecting the electric field between the plates. Additionally, keeping your hands away from the device and avoiding direct contact with the cavity structure minimizes interference. setup can be sensitive to static charges, and touching the cavity or plates may introduce additional capacitance or grounding, leading to inaccurate results.

S.No	Sample	Measured Capacitance (pF)
1.	Air	0.81
2.	Drinking Water	0.86
3.	Tap Water	0.98
4.	Sanitizer	1.11
5.	Coca Cola	1.01
6.	Orange Juice (Carbonated)	0.94
7.	Mango Juice	0.92
8.	Lychee Energy Drink	0.97

Table 3.1 Capacitance Measurement of Various Samples

6. Minimizing Contact with Wire Leads:
The wire leads connecting the capacitor plates to the Arduino analog pins are sensitive to touch. Physical contact can introduce unintended capacitance or create grounding issues, which will impact the readings. Therefore, handle the device carefully, keeping the leads insulated from any direct contact. This ensures that the only capacitance measured is from the cavity and the liquid sample, without additional disturbances.
By following these steps carefully, you can obtain precise capacitance readings for each liquid sample. The accuracy of this process allows your device to effectively demonstrate how different liquids, with their unique dielectric constants, influence capacitance, thereby achieving the objective of identifying and characterizing materials based on their dielectric properties.

Following the above steps readings were taken for different samples . Results are as shown above.

CHAPTER 4

CONCLUSION

5.1 Conclusion

The purpose of this project was to design and construct a capacitive sensing device, utilizing an Arduino Uno microcontroller as the main unit for processing the analog sensor values, to measure and analyze the dielectric properties of various liquid samples. Through the combination of hardware and software, the device successfully measured capacitance changes corresponding to different liquid samples, and the results were displayed on an I2C-enabled 16x2 LCD display. this project successfully achieved its goals of designing a capacitive sensing device that can measure and analyze the dielectric properties of various materials. The combination of physical construction, and Arduino-based data acquisition allowed for a thorough validation of the results. The device's design and functionality suggest potential applications in fields where dielectric characterization is needed, such as material science, chemical analysis, and environmental testing. This project highlights the value of integrating experimental techniques with digital tools to enhance accuracy and understanding in electronics-based research.

CHAPTER 5

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