Case Study: Scanning Acoustic Microscopy (SAM): Limits of Operation. Water Quality Monitoring.

Shokhrukh Khamidov 22309808, Ranveer Patil 22305107,
Nevil Rafaliya 22305913, Naimish Savaliya 22305937, Jeel Kishorbhai 22304620

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Abstract

This case study presents the development and implementation of an intelligent system designed to measure and visualize water quality, specifically focusing on turbidity levels. Leveraging the principles of Scanning Acoustic Microscopy (SAM), the system integrates advanced imaging techniques with real-time data acquisition and display capabilities. The core objective is to provide an accurate, user-friendly solution for monitoring water quality, facilitating prompt intervention in case of contamination.

The intelligent system employs an Arduino-based setup equipped with turbidity sensors interfacing with the WINSAM software for enhanced data analysis and visualization. Turbidity, a critical indicator of water quality, is measured by quantifying the cloudiness caused by suspended particles such as clay, silt, and organic matter. By utilizing high-frequency ultrasound waves, SAM provides detailed insights into the internal features of water samples, including the presence of contaminants.

The methodology includes setting up the SAM with appropriate sensors, calibrating the system to ensure accurate measurements, and developing a real-time display interface using a 16×2 LCD. The system also incorporates essential hardware components such as resistors, jumper wires, and power adapters to ensure reliable operation.

Expected outcomes of this project include precise turbidity measurements, real-time monitoring capabilities, and enhanced decision-making for water management. The successful implementation of this system demonstrates the potential of integrating SAM technology with intelligent systems to address environmental monitoring challenges, providing a scalable and effective solution for water quality management.

1 Introduction

In recent years, the increasing concern over water quality has driven the need for advanced monitoring systems capable of providing accurate and real-time data. Water quality is a critical factor affecting public health, environmental sustainability, and industrial processes. Among various parameters, turbidity serves as a key indicator of water quality, reflecting the presence of suspended particles such as clay, silt, organic matter, algae, and microorganisms. High turbidity levels can signify potential contamination and necessitate immediate action to ensure safety and compliance with regulatory standards.

This report explores the development of an intelligent system designed to measure and visualize water turbidity using Scanning Acoustic Microscopy (SAM). SAM is a non-destructive imaging technique that utilizes high-frequency ultrasound waves to analyze the internal structure and properties of materials. By integrating SAM with modern sensor technology and data visualization tools, this project aims to deliver a robust solution for real-time water quality monitoring.

The intelligent system leverages the capabilities of an Arduino-based setup, incorporating turbidity sensors to capture and relay data to the WINSAM software. This integration enables detailed analysis and visualization of water quality parameters, providing users with an intuitive interface to monitor and interpret turbidity levels. The use of SAM enhances the system's ability to detect and analyze internal features of water samples, such as the distribution and concentration of suspended particles.

This project is motivated by the need to address the limitations of traditional water quality monitoring methods, which often involve manual sampling and laboratory analysis. By offering a real-time, automated solution, the intelligent system aims to improve the efficiency and accuracy of water quality assessments, facilitating timely decision-making and intervention.

The following sections of this report will detail the methodology, hardware setup, software integration, and expected outcomes of the intelligent system. By demonstrating the practical application of SAM in water quality monitoring, this project contributes to the ongoing efforts to safeguard water resources and promote sustainable management practices.

2 Materials and Methods

2.1 Materials

- Arduino UNO R3 DIP Board: A microcontroller board used for interfacing with the turbidity sensor and managing data acquisition.
- Turbidity Sensor Module: A sensor designed to measure the cloudiness or haziness of water samples, providing real-time turbidity levels.
- 16×2 LCD Display: A display module used to visualize the measured turbidity levels.
- Hard Jumper Wires (1 meter): Used for establishing connections between various components.

- 10k Variable Resistor (Potentiometer): Used to adjust the contrast of the LCD display.
- 9V Battery Snap Connector to DC Male Power Adapter Cable: Provides power to the Arduino board.
- 9V Battery Module: Supplies power to the Arduino system.
- 100 Ohm Resistors: Used in the circuit to limit current and protect components.
- Male-to-Female Jumper Wires (10 cm): For connecting the sensor and display to the Arduino board.
- MB102 Breadboard: A breadboard used for prototyping and assembling the circuit.
- Panel with Resin Chips Coated with Thin Layer of Copper: Used as samples for WinSAM to assess signal clarity and turbidity effects.

2.2 Methods

The WinSAM (Water Immersion Scanning Acoustic Microscopy) system uses high-frequency ultrasound waves to scan and visualize internal structures of a sample. It consists of a transducer that emits and receives ultrasound waves, a water tank where the sample is immersed, and a data processing unit that generates detailed images based on the acoustic signals.

Water is crucial in the WinSAM system as it serves as an effective medium for transmitting ultrasound waves between the transducer and the sample. It provides a consistent medium, minimizing signal distortion and ensuring accurate imaging. Additionally, water helps maintain a stable temperature, which is important for consistent acoustic properties and reliable measurements.

Initially, the WinSAM system was filled with distilled water with a conductivity of 1 µS/cm. Baseline readings were taken on June 10th to establish a control measurement. The water was left in the system for two weeks, and on June 25th, another set of readings was conducted to observe any changes in signal clarity due to potential turbidity increase over time.

The WinSAM system was configured with specific settings for both the initial and follow-up readings:

- **XGate1**: A broad gating window used in scanning acoustic microscopy to capture a wide range of signals shown in Figure 1 (Left side box). It ensures that the primary signal of interest falls within the captured data range. Set with a start position of 359 nanoseconds (ns) and a length of 3000 ns. The processing was set to ’Peak’ to focus on the highest signal values, and the polarity was set to ’Bipolar’ to consider both positive and negative parts of the signal. The spatial resolution was maintained at 50.00 micrometers per pixel (µm/Pixel).

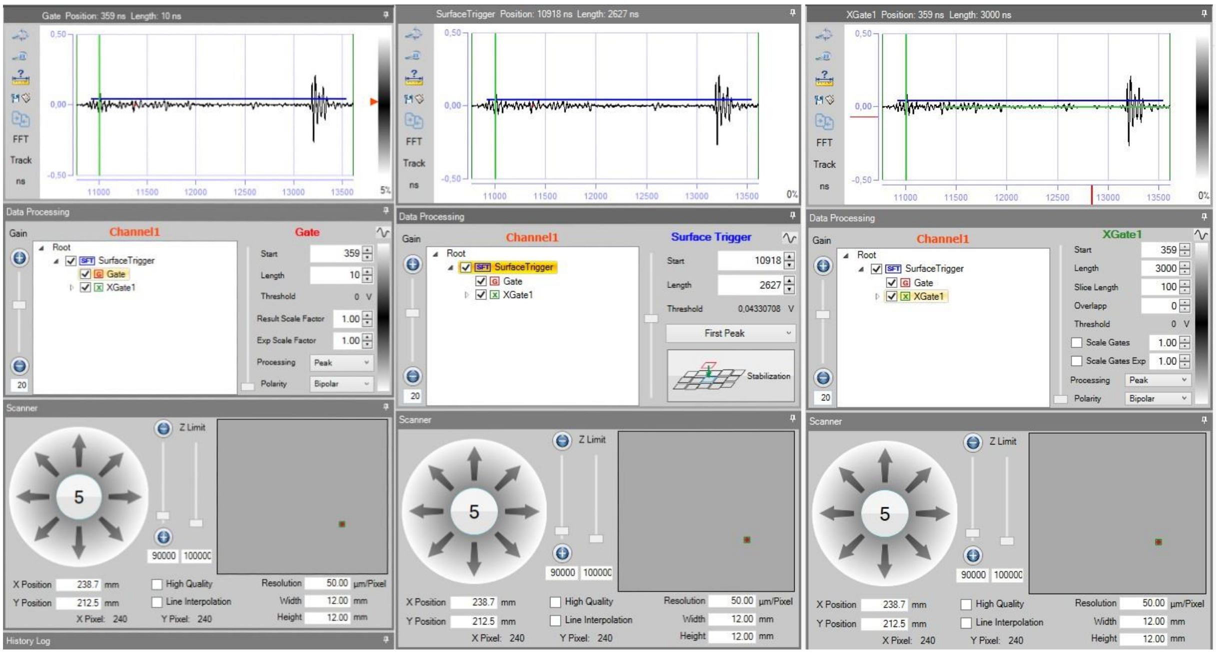

Figure 1: WinSAM. Gate window tuning interface.

- **Second Gate**: A narrower window compared to XGate1, focusing on a very specific part of the signal, shown in Figure 1 (Center box). Configured with the same start position of 359 ns but with a much shorter length of 10 ns, this narrow gate also used 'Peak' processing and 'Bipolar' polarity with the same spatial resolution.
- **Surface Trigger**: Used to detect the initial surface of the sample or a significant reflection point, also shown in Figure 1 (Right side box). Set to start at 10918 ns with a length of 2627 ns and a threshold of 0.04330708.

The WinSAM system is capable of performing various types of scans to analyze different aspects of samples [3]:

- **A-Scan (Amplitude Scan)**: A one-dimensional scan that measures the amplitude of the reflected signal as a function of time or depth.
- **B-Scan (Brightness Scan)**: A two-dimensional cross-sectional scan that provides an image of the sample's internal structure along a single line.
- **C-Scan**: A two-dimensional scan that maps the amplitude of the reflected signal across a plane at a constant depth.
- **Z-Scan**: This scan measures the depth profile of the sample providing information about the internal structure as a function of depth.

2.2.1 Scan Type Used in This Experiment

In this experiment, a C-Scan was employed. This type of scan was chosen because it provides a comprehensive two-dimensional image of the sample's surface or an internal plane at a constant depth. The C-Scan was ideal for comparing the initial and aged water conditions as it allowed for detailed visualization of any changes in the water's turbidity and its effects on the signal clarity over time.

Simultaneously, an Arduino-based turbidity sensor setup was prepared. In general, the measurement of turbidity is split into two basic methodologies: turbidimetry, in which the degree of transmission of light is determined, and nephelometry, in which the degree of light-scattering is evaluated [1]. The turbidity sensor that manages to operate these procedures was connected to the Arduino UNO board with the 16×2 LCD display integrated using jumper wires and a potentiometer to adjust the display contrast. The components were assembled on an MB102 breadboard to facilitate easy connections and modifications. The turbidity sensor was connected to the analog input pin of the Arduino, while the LCD was connected to the digital pins.

Initial turbidity readings of the distilled water were taken using the turbidity sensor, and the results were recorded for comparison. Two samples were prepared: one sample of distilled water left undisturbed for two weeks, and another sample with added dirt also left for two weeks. After the two-week period, turbidity readings from both samples were taken using the sensor.

For the software configuration, the Arduino was programmed using the Arduino IDE to read the voltage output from the turbidity sensor, convert it to NTU (Nephelometric Turbidity Units), and display the results on the LCD. The WINSAM software was utilized to analyze the initial and aged water readings.

Calibration of the turbidity sensor was conducted using standard turbidity solutions to ensure accurate measurements. Sensor readings were compared with known turbidity values to adjust the system for precise results. During testing, various water samples with different turbidity levels were analyzed to validate the system's performance. Real-time data was monitored and recorded using both the LCD display and the WINSAM software.

The data was analyzed by comparing pictures from WinSAM taken with clear water and after the two-week period. Additionally, turbidity values measured by the Arduino sensor from clear water and after two weeks were compared. These comparisons allowed for the assessment of changes in water quality over time, focusing on the effects of increased turbidity on the readings from both the WinSAM and the turbidity sensor.

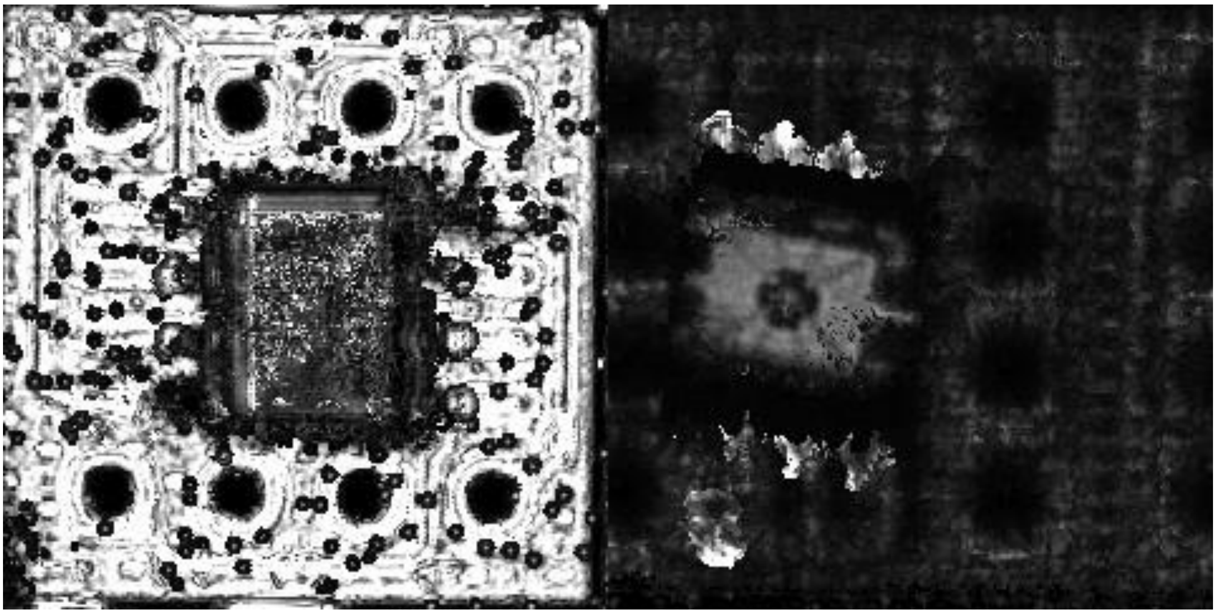

Figure 2: C-Scan on Distilled Water (Left side) and on 2-weeks old Water (Right side). 10/06/2024 and 25/06/2024.

3 Results

3.1 WinSAM C-Scans

On June 10, 2024, a series of C-Scans were performed on distilled water with results shown in Figure 2 (Left side). The scans displayed clear and well-defined images of the sample, with minimal background noise and high signal clarity, indicating the water was free of significant turbidity or contaminants. The central features and surrounding details of the sample were clearly visible, with strong and consistent signal peaks.

After two weeks, on June 25, 2024, a second series of C-Scans was conducted on the same distilled water which had been left undisturbed. Example is shown in Figure 2 (Right side) The scans showed a significant reduction in image clarity compared to the initial scans. Increased background noise and a darker overall appearance were observed, indicating higher turbidity levels. The central features and surrounding details were less visible, and the signal peaks were weaker and more diffuse.

3.2 Arduino-Based Turbidity Sensor Readings

On June 10, 2024, initial readings of the distilled water were taken using the Arduino-based turbidity sensor. The sensor value was converted to standardized value (called “voltage”) using the formula:

```
float voltage = sensorValue * (10 / 1023.0);
```

The sensor displayed a voltage of 9.1 V indicating very low turbidity and high water clarity.

After two weeks, on June 25, 2024, readings of the same distilled water were taken again. Using the same conversion formula, the sensor displayed a voltage of 8.8 V. This slight decrease in voltage indicates a minor increase in turbidity over the two-week period.

These results provide a comparative view of the changes in water quality over time, as detected by both the WinSAM C-Scans and the Arduino-based turbidity sensor. The WinSAM scans visually illustrate the increased turbidity, while the sensor readings quantitatively reflect the changes in water clarity.

4 Discussion

4.1 Introduction and Research Question

This study aimed to determine the impact of water turbidity on the performance of the WinSAM system and compare it with the readings from an Arduino-based turbidity sensor. The primary research question addressed was: How does increased turbidity over a period of two weeks affect the clarity and accuracy of readings obtained from WinSAM, and how effective is an Arduino-based turbidity sensor in detecting these changes?

4.2 Discussion of Results

The comparison of C-Scans taken on June 10, 2024, and June 25, 2024, revealed a significant degradation in image clarity over the two-week period. Initially, the scans displayed clear and well-defined images with minimal background noise and high signal clarity. However, after two weeks, the images showed increased background noise, darker overall appearance, and less visible central features and surrounding details. This degradation suggests that the water's turbidity increased, likely due to the accumulation of suspended particles and microbial growth.

The likely cause of increased turbidity includes suspended particles and microbial growth. Over time, even distilled water can support microbial growth, leading to the formation of biofilms that interfere with the transmission of acoustic signals. Additionally, dust and other airborne particles could have settled into the water, further contributing to turbidity. These particles scatter and absorb the acoustic signals, leading to weaker and more diffuse signal reception [2].

Chemical changes in the water composition could also have contributed to the reduced signal clarity. Contaminants from the environment or handling might have altered the water's properties, increasing the absorption and scattering of acoustic waves. For example, slight changes in pH, dissolved minerals, or organic compounds could increase the absorption and scattering of acoustic waves, thus degrading the signal.

Environmental factors such as a decrease in water level and temperature fluctuations (from 178 to 216 units) likely impacted the readings. The decreased water level might have introduced air bubbles, changing the acoustic path and scattering the signals. The temperature increase could have altered the water's viscosity and density, affecting the speed and attenuation of sound waves.

Additionally, equipment factors must be considered. The transducer might have experienced wear or slight misalignment over time, affecting the consistency of signal transmission and reception. Calibration settings might have drifted, impacting the accuracy of the readings.

The Arduino-based turbidity sensor readings indicated only minor changes in water clarity over the two weeks. Initially, the sensor displayed a voltage of 9.91 V indicating very low turbidity. After two weeks, the voltage decreased slightly to 9.76 V suggesting a minor increase in turbidity. The sensor's limited sensitivity and resolution likely contributed to its inability to detect significant changes in water quality. Its design primarily detects large changes in turbidity, making it ineffective for monitoring subtle variations.

4.3 Strengths and Limitations

This study's strengths include the use of both qualitative (WinSAM C-Scans) and quantitative (Arduino-based turbidity sensor) methods to assess water quality changes. The combination of these approaches provided a comprehensive understanding of the effects of increased turbidity over time. However, several limitations should be noted. The decrease in water level and temperature fluctuations were not controlled, potentially impacting the results. The Arduino-based turbidity sensor's limited sensitivity and resolution highlight its unsuitability for detecting minor changes in water clarity.

4.4 Future Research

Future research should focus on addressing the limitations identified in this study. Controlling environmental factors such as water level and temperature can help isolate the effects of turbidity on the WinSAM readings. Developing and employing more sensitive turbidity sensors capable of detecting subtle changes in water quality would improve monitoring accuracy. Additionally, exploring advanced filtering techniques and adaptive gating in the WinSAM system could enhance signal clarity and reduce noise.

Further studies could also explore the use of alternative imaging and sensing technologies to complement the capabilities of WinSAM and the Arduino-based turbidity sensor. For example, combining acoustic imaging with optical or chemical sensing methods might provide a more comprehensive understanding of water quality. Developing automated systems for regular calibration and maintenance could also help ensure consistent performance and reduce the potential for human error.

5 Conclusion

This study demonstrated that increased turbidity over a two-week period significantly degraded the clarity and accuracy of WinSAM readings. The Arduino-based turbidity sensor, however, failed to detect these changes effectively due to its limited sensitivity and resolution. The findings highlight the need for robust and sensitive monitoring systems to ensure accurate water quality assessments. Future research should address the identified limitations and explore advanced methods to improve the reliability and accuracy of water quality monitoring technologies.

6 Literature

References

[1] Anthony J Parsons Ben GB Kitchener, John Wainwright. A review of the principles of turbidity measurement. *SAGE journals*, 41(5):620–642, 2017.

[2] Malik MF Chaudhry FN. Factors affecting water pollution: A review. *Journal of Ecosystem and Ecography*, 7(1):1–3, 2017.

[3] Klaus Kraemer Silvia U. Fassbender. Acoustic microscopy: a powerful tool to inspect microstructures of electronic devices.

7 Appendix

The following code outlines the algorithm used for the Arduino and its turbidity sensor. It includes functions for reading data from the sensor and displaying the results on an LCD screen.

```
#include <LiquidCrystal.h>
// #include <LiquidCrystal_I2C.h>

LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
//LiquidCrystal_I2C lcd(0x27, 16, 2);


void setup() {
  // def bits
  lcd.begin(16, 2);
  lcd.print("Turbidity meter:");
  Serial.begin(9600);
```

```
}

// OK lets do
void loop() {
  int sensorValue = analogRead(A5);
  // convert the analog reading (which goes from 0 - 1023)
  float voltage = sensorValue * (10 / 1023.0); //7.93 i mpped
  // print out in termi

// Clear the second row of the LCD
  lcd.setCursor(0, 1);
  // lcd.print("                    "); // clear previous val

  // print the voltage   to the LCD
  lcd.setCursor(0, 1);
  lcd.print(voltage);
  lcd.print(" <- Units");

  Serial.println(voltage);

  delay(100);

}
```

Listing 1: Arduino Code for Turbidity Sensor

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

void loop() {
  int sensorValue = analogRead(A0);
  float voltage = sensorValue * (10.0 / 1023.0);
  Serial.println(voltage);
  delay(1000);

}
```

8 Acknowledgements

Student name	Contribution	Signature with Date
Shokhrukh Khamidov	Contributes towards defining the Project Objective, Research, Data Gathering, Arduino Assembly/Coding, Report generation, Literature Review, Formatting and Deployment.	
Ranveer Patil	Contributes towards defining the Project Methodology, Material and Equipment list preparation, Data Gathering, Presentation design and Theoretical framework.	
Nevil Rafaliya	Contributes towards the Testing Equipment, Assistance in Data Gathering and Evaluation.	
Naimish Savaliya	Contributes towards the Testing Equipment, Assistance in Framework design and Evaluation.	
Jeel Kishorbhai	Contributes towards the Testing Equipment, Assistance in Data Gathering and Presentation design.	