Design and Development of an Instrumentation System to Monitor Water Quality

A Thesis

submitted by

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CERTIFICATE

This is to certify that the thesis titled **Design and Development of an Instrumentation System to Monitor Water Quality** submitted by Lakshmi Prasanya Devarakonda , to the Indian Institute of Technology, Madras, for the award of the degree of Bachelor of Technology and Master of Technology (DUAL DEGREE), is a bonafide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

Water is essential to human life and the health of the environment. Water quality is important not only to protect public health,water provides ecosystem habitats, is used for farming, fishing and mining, and contributes to recreation and tourism. Water quality issues influence human and environmental health, so the more we monitor our water the better we will be able to recognize and prevent contamination problems.

Monitoring your water quality by having it tested regularly is an important part of maintaining a safe and reliable source. Testing the water allows a knowledgeable approach to address the specific problems of a water supply. Monitoring helps ensure that the water source is being properly protected from potential contamination, and that an appropriate treatment system is selected and is operating properly. This will assist you in making informed decisions about your water and how you use it, ensure you are using water suitable for your intended agricultural use, ensure that your drinking water is safe, help determine the effectiveness of your water treatment system. A design is proposed to address such issues. The output specifies the quality of water and turbidity. A prototype of the design has been developed and tested in the laboratory. Test results validate the efficacy of the technique presented.

Such a system can be used at both industrial level as well as household level. Ensuring the user is aware of the type of water by its turbidity is the aim of this project. Since it is cost effective and easy to use such a model can be applied to a larger extent.

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ABBREVIATIONS

NTU	Nephelometric Turbidity Unit
UF	Ultra Filtration
JTU	Jackson Turbidity Unit

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

Water pollution is one of the biggest fears for the green globalization. In order to ensure the safe supply of the drinking water the quality needs to be monitored. Turbidity is an extremely useful indicator that can yield valuable information quickly, relatively cheaply and on an ongoing basis. Measurement of turbidity is applicable in a variety of settings, from low-resource small systems all the way through to large and sophisticated water treatment plants. This measururement also makes the quality of water in a storage tank be monitored so that the user is aware of the changes in conditions inside the tank and at treatment plant level this system can provide information regarding the water turbidity and subsequent sorting and treatment.

1.2 PROBLEM STATEMENT

Design and Development of a Water Quality Monitoring System that could provide reliable information to the user.

1.2.1 OBJECTIVE

To be able to identify and classify samples of different turbidity values so as to facilitate sorting for their respective treatment procedures and quality monitoring.

1.2.2 SCOPE

There can be any kind of intrusion in between treatment plant and end consumers due to various reasons. The system when interfaced with household water tanks it can serve as an entry check to ensure if the incoming water is safe enough for use or if there is any sort of contamination. At the industrial level the system can be utilized for monitoring and sorting purposes as well.

1.2.3 PRINCIPLE

WATER QUALITY IS ANALYSED BASED ON TURBIDITY AS PARAMETER.

The project deals with design and development of a system for monitoring water quality. Its operation is based on the principle that the intensity of the light scattered by the suspended matter is proportional to its concentration.

1.3 NEED FOR SUCH A SYSTEM

This sensor can be used as a part of a low cost sensor network consisting of different types of sensors (pH, temperature, chloride, etc) to provide water quality information to consumers. Fusing on-line multi sensor measurements, the system can provide useful information regarding hazardous agents and waterborne pathogens contaminants of household drinking water raising awareness and encourage better water-handling.

The system is applicable from a simple household storage tanks to well built water treatment plants. It provides information about the current health of the water body, whether the water meets the designated use and how it has changed over time. Information gathered can be used to suggest that the water body requires improvement to meet its designated use and lead to actions to protect and restore the health of the water body. In addition, water quality monitoring can help with water pollution detection, discharge of toxic chemicals and contamination in water. One of the reasons for this is unawareness in public and administration and the lack of water quality monitoring system which creates serious health issues. As water is the most important factor for all living organisms it is necessary to protect it and water quality analysis is first step taken in rational development and management of water resources.

1.4 CHALLENGES

The system helps to understand if water supplied in a region is safe for drinking or not. But the model works well under static conditions. When there is continuous flow of water the readings would vary fast enough that the user might not be able to capture the small irregularities in the measurements.

CHAPTER 2

LITERATURE SURVEY

2.1 BACKGROUND

2.1.1 THEORY OF SCATTERING

A directed beam of light remains relatively undisturbed when transmitted through absolutely pure water, but even the molecules in a pure fluid will scatter light to a certain degree. Therefore, no solution will have a zero turbidity. In samples containing suspended solids, the manner in which the sample interferes with light transmittance is related to the size, shape and composition of the particles in the solution and to the wavelength (color) of the incident light.

Effect of size of the particle and wavelength of the incident light on scattering:

a. Large particles scatter long wavelengths of light more effectively than they scatter short wavelengths.

b. Small particles scatter short wavelengths of light more effectively than large particles but have less effect on the scatter of longer wavelengths.

Rayleigh scattering : for particles upto size of 1/10 th of the wavelength [1].
Local E field produced by the wave is approximately uniform at any instant. E field produces dipole in a particle,since the E oscillates dipole oscillates and thereby radiating in all directions. When a particle is much smaller than the beam of light, the scattering is fairly symmetrical in all directions .
If the wavelength of light doubles, the scattering efficiency decreases by a factor of 16. Thus, 450-nm wavelength will scatter 16 times more than 900-nm wavelength interacting with the same particle. Ligth intesity at right angles is half the forward

scatterd light. When particles size exceeds 10% of the wavelength of light then this theory breaksdown and Mie theory is applicable[1]. Intensity of light is strongly dependent on size of particle than the wavelength. The spatial distribution of scattered light depends on the ratio of particle size to wavelength of incident light. The larger the particle becomes, however, the more light that will be scattered forward. However scattering in this range of particle sizes differs from Rayleigh scattering in several respects : it is roughly independent of wavelength and it is larger in the forward direction than in the reverse direction.

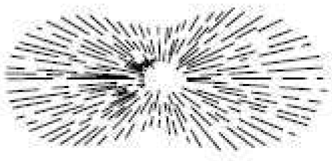

Fig 2.1: scattering by a smaller particle [2]

Particles much smaller than the wavelength of incident light exhibit a fairly symmetrical scattering distribution with approximately equal amounts of light scattered both forward and backward.

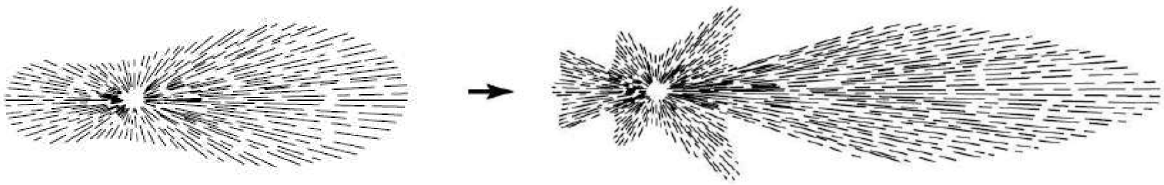

Fig 2.2: scattering by larger particles [2]

As particle sizes increase in relation to wavelength, light scattered from different points of the sample particle create interference patterns that are additive in the forward direction. This constructive interference results in forward-scattered light of a higher intensity than light scattered in other directions. Hence in larger particles (larger than the wavelength of light) scattering in extremely concentrated in forward direction[3][4]. Therefore fixing the receiver at an angle of 90° respect to the emitter will reduce the effect of the particle size.Hence providing sensitivity to a broad range of particle sizes.

2.1.2 EXISTING TECHNOLOGIES

The light produced from the interaction of the incident light and the sample volume will be detected by the photodetectors and as a result the electronics signal produced is then converted to a turbidity value. The location of the detector in the turbidimeter varies according to the design configuration of the instrument.

2.2 MONITORING TECHNOLOGIES

It is important to understand that samples with different characteristics such as particle absorption, reflectivity, size and size distribution will interact differently with the wavelengths of different light sources. Thus, different turbidity measurement technologies often deliver different results on the same sample.

Turbidity monitoring technologies can be categorized by three design criteria[3][4]:

a) The type of incident light source used
b) The detection angle for the scattered light
c) The number of scattered light detectors used.

Three **types of light sources** are commonly used in turbidimeters:
Incandescent, Light emitting diode (LED), and Laser diodes[4].

Incandescent light sources emit a broad spectrum of light that includes shorter wavelengths that are better suited to detection of smaller particles.

Common infrared LEDs (IR) used in turbidity measurements emit 830-890 nanometer (nm) light that is typically not absorbed by visible color in the sample, eliminating a common source of error. However, this technology does not provide enough sensitivity to detect ultra low turbidity changes in membrane effluent water.

Laser-based light sources are very sensitive to small changes in turbidity and are often used to monitor the performance of filters producing ultrapure water such as is commonly used in many industrial processes.

The **detection angle** is formed between the centerline of the incident light beam and the centerline of the detector's receiving angle.

A 90-degree detection angle is often referred to as the nephelometric detection angle and is the most common detection angle because of its sensitivity to a broad range of particle sizes[4].

The attenuated detection angle is 180-degrees relative to the incident light beam so it measures the attenuation of the incident light beam due to both light scatter and absorption.

The backscatter detection angle uses a detector that is geometrically centered at an angle of between 0- and 45-degrees relative to the directional centerline of the incident light beam. This angle is sensitive to light that is reflected in the direction of the incident light source, which is characteristic of extremely high turbidity samples. The 90° detection angle is considered to be the most sensitive angle to measure scattered light and it is recognized by EPA (Environmental Protection Agency) Method 180.1 [5].

Multiple detection angles is a ratio approach that uses a combination of detectors that together determine a turbidity value[4].

Dual light source, dual detector measurement technologies use a combination of light sources that are geometrically oriented at 90-degree angles to each other. The detectors are also oriented at 90-degrees to each other and at 90- and 180-degrees to each of the light sources. These different combinations of optical elements provide a turbidity measurement that is compensated for color, absorption, fouling of the optics, and any optical changes that can occur.

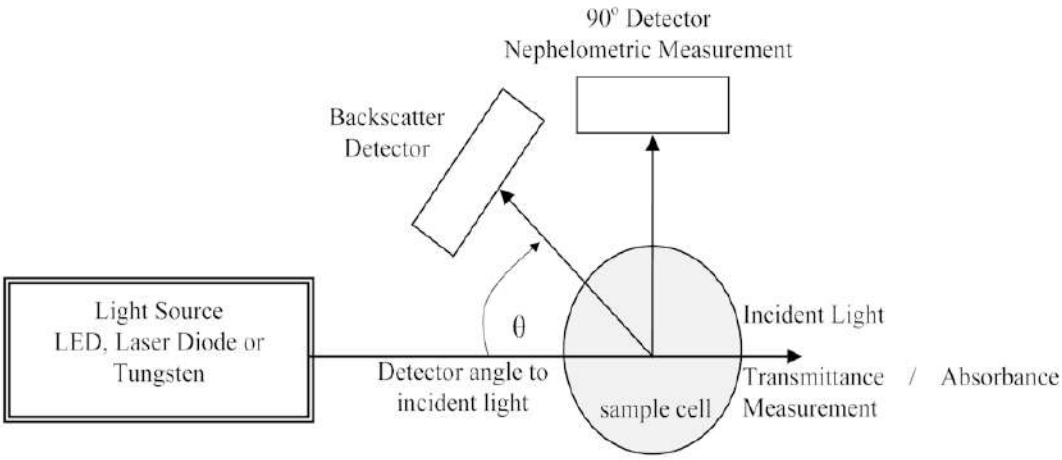

Fig 2.3: configurations for measuring turbidity [6]

2.3 METHODS TO MEASURE TURBIDITY

Nephelometry and Turbidimetry[1]

Turbidity is caused by suspended and colloidal particles in water. Particles can be inorganic and organic:clay ,silt, mud, silica, rust, calciumcarbonate, algae, bacteria,organic material. The particles absorb and scatter light.

In Turbidimetry, light passing through the sample is measured.

In Nephelometry, light scattered by suspended particles in a sample is measured. It is more sensitive for very dilute suspensions. The analytical methods employ common electric photometers that can measure light intensity. The turbidimeter or nephelometer mainly consists of four parts — light source, optical components (e.g. slit), sample compartment and a photocell for the measurement of light either transmitted through the sample or scattered from the suspended particles in the sample. The photocell detects light and an electronic amplifier measures the light intensities.

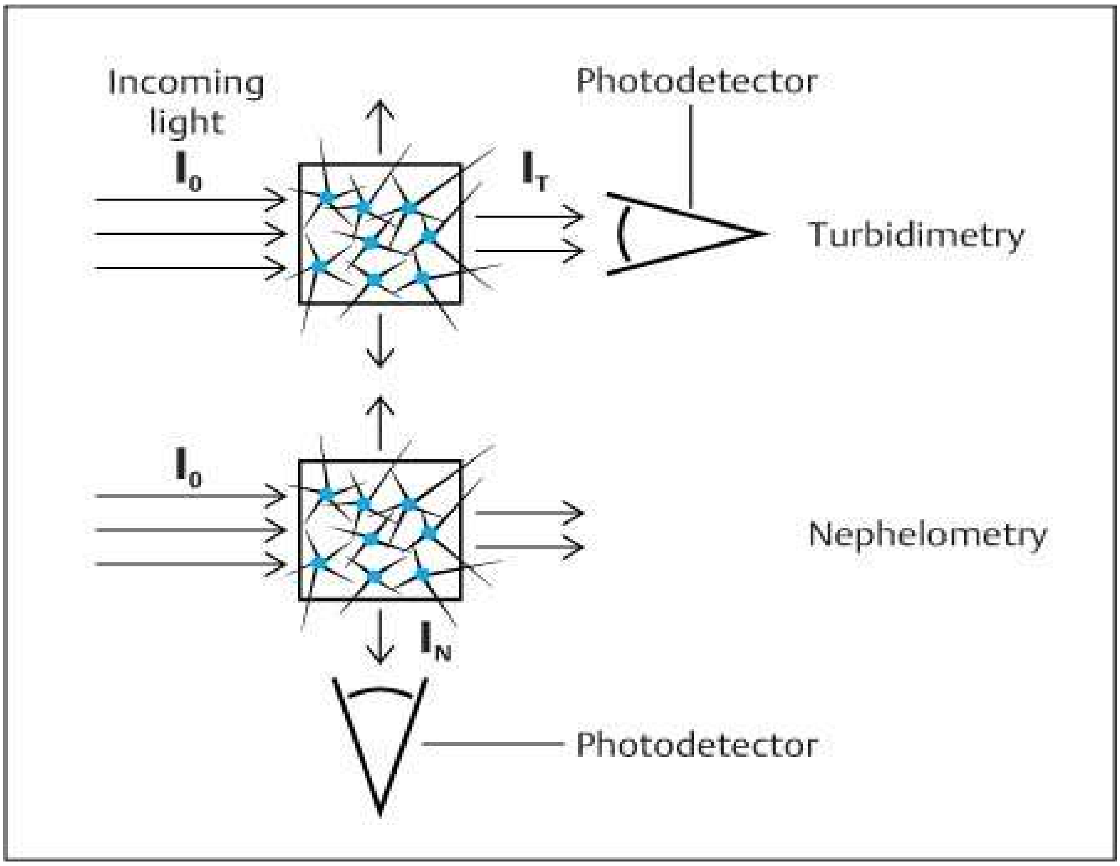

Fig 2.4: Turbidimetry and Nephelometry[7]

2.4 STANDARDS AND UNITS

2.4.1 Turbidity Units

The standard Turbidity unit is called Nephelometric Turbidity Unit (NTU) because of the use of nephelometric method of measurement. The NTU has generally replaced the previous unit of 'Jackson candle turbidity units (JTU)[8][13].

2.4.2 Typical Turbidity Values for different waters

Drinking water quality standards are determined according to World Health Organization [9] guidelines for drinking-water quality as well as other pertinent organizations (i.e. EU , USEPA). These organizations set the standards for drinking water quality parameters and indicate which microbiological, chemical and indicator parameters must be monitored and tested regularly in order to protect the health of the consumers and to make sure the water is wholesome and clean.

Type of water	NTU
Surface Water (Rainy season)	1000 and above
Treated tap water	1 to 2
De-mineralised water	0.1 to 0.5
Water filtered through membrane filter	0.05 or less

Table 2.1 : Types of water and their turbidity

A Turbidity of 1 NTU for drinking water is accepted and above 5 NTU consumer acceptance decreases[10]. Turbidity may change during sample transit and storage.

2.5 WATER QUALITY ANALYSIS AND MONITORING

Theofanis P. Lambrou and Christos G. Panayiotou in the paper ,"A Low-Cost System for Real Time Monitoring and Assessment of Potable Water Quality at Consumer Sites"[11] discussed of the design of a low cost water quality monitoring system. Based on selected parameters a sensor array is developed along with several microsystems for analog signal conditioning, processing and remote presentation of data. Finally, an algorithm for fusing on-line multi sensor measurements is developed to assess the water contamination risk. Such implementation is suitable for large deployments enabling a sensor network approach for providing spatiotemporally rich data to water consumers, water companies and authorities.

Divya Bhardwaj and Neetu Verma in their journal,"Research Paper on Analysing impact of Various Parameters on Water Quality Index"[12] mentioned about various parameters such as pH, electrical conductivity, turbiidty and dissolved oxygen that effect the water quality index. Apart from discussing the effect of such parameters on water quality, the specifications for these parameters to be suitable for agricultural needs, industrial use, aquatic organisms and drinking purposes are also studied in order to provide quality information regarding the water available.

Óscar Sampedro, José Ramón Salgueiro in the article titiled ,"Turbidimeter and RGB sensor for remote measurements in an aquatic medium "[13] proposed a design of turbidimeter with nephelometer method to analyse the quality of water over a time period. The calibration for temperature, turbidity(to relate signal output to turbidity scale) and RGB(to relate output signal to the color of the sample). The turbidimeter was tested during two months offshore in a bay of northwestern Spain obtaining a periodic turbidity daily signal from the water. On the other hand, the RGB sensor pointed out that the marine suspended particles were primarily green. These data demonstrated that the apparatus detected the diel vertical migration of phytoplankton.

CHAPTER 3

EXPERIMENTAL SET UP

The circuit is designed using near infrared laser source with peak emission wavelength at 650 nm with a photodiode detector.

3.1 SYSTEM ARCHITECTURE

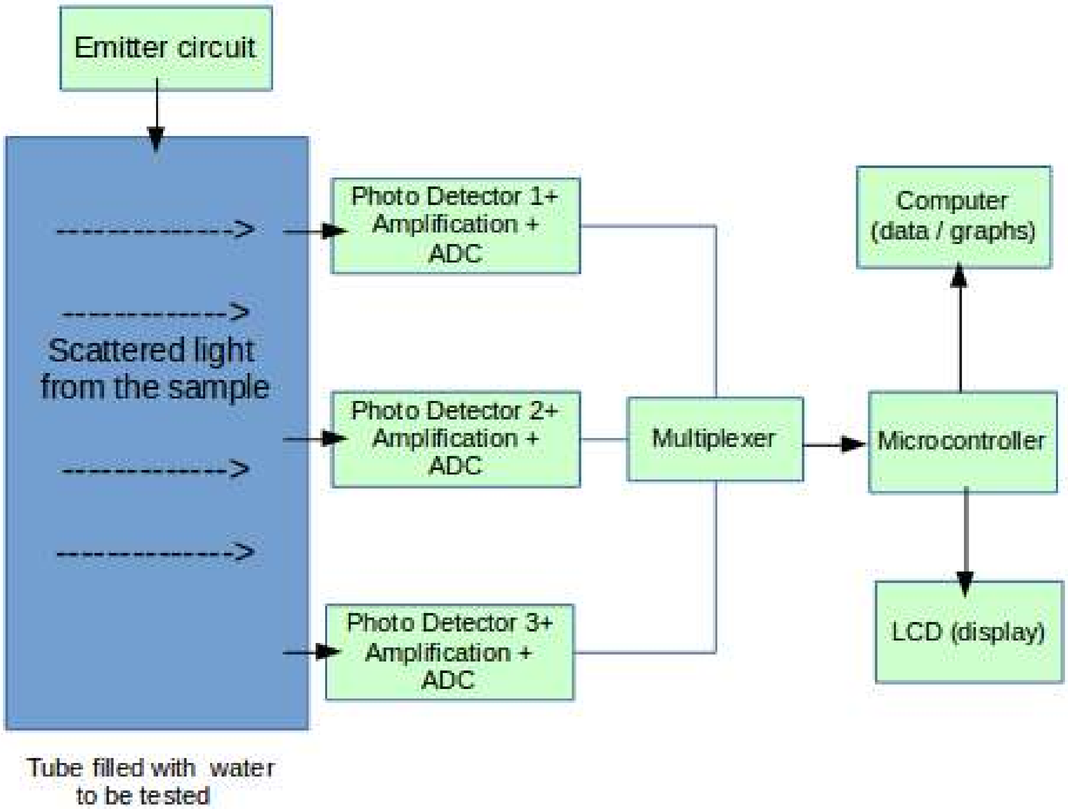

Fig 3.1: system architecture

3.2 WORKING OF THE MODEL

The light emitted from the laser passed through the sample. The scattered light from the particles inside the sample responsible for the turbidity is then detected by the TCS34725 sensor and corresponding digital output is fed to the Arduino through I2C expander. Thereafter the results can be taken from the LCD or from the computer.

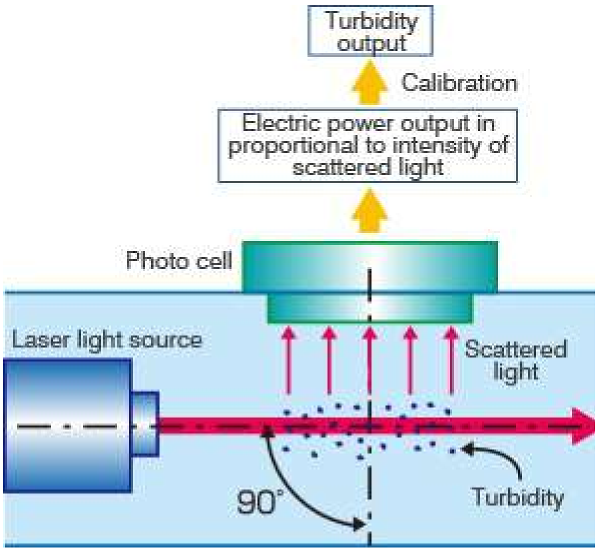

Fig 3.2: working of the model [3]

Unlike the commercially available turbidity meters, which are relatively expensive and bulky, the proposed device is small-sized, low power,table-top set up(presently), lightweight,easy to use and inexpensive. Laboratory tests of the device have yielded satisfactory repeatability and precision.

3.3 SENSOR MODULE

The device provides a digital return of red, green, blue (RGB), and clear light sensing values. An IR blocking filter, integrated on-chip and localized to the color sensing photodiodes, minimizes the IR spectral component of the incoming light and allows color measurements to be made accurately.

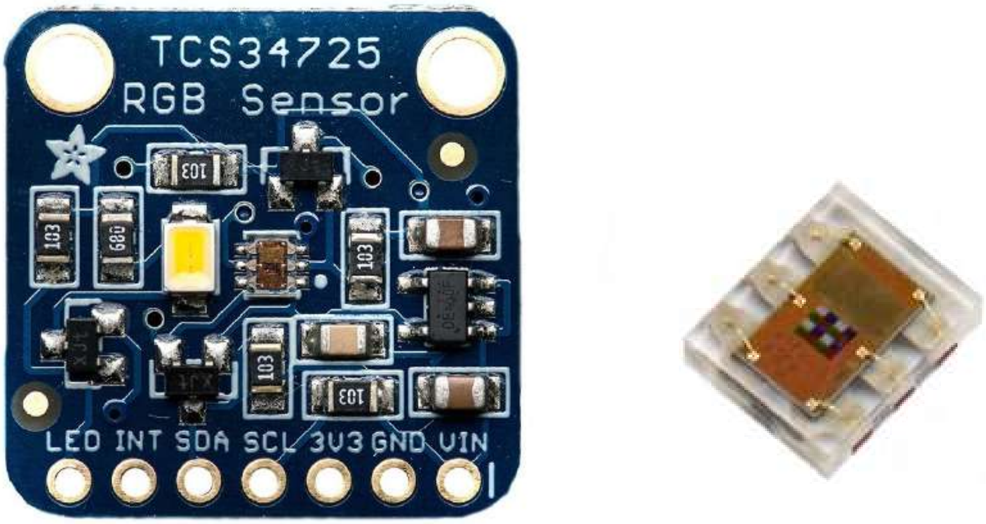

Fig 3.3: color sensor and photodiode array [14]

The TCS3472 light-to-digital converter (sensor)contains a 3 ×4 photodiode array. RGB filters filter out the particular color which is taken in by the photodiodes[15]. It produces photocurrent by generating electron-hole pairs, due to the absorption of light in the in the depletion region. The photocurrent thus generated is proportional to the absorbed light intensity. The photodiode currents thus obtained is connected to ADC for a digital output. The digital output is communicated to other devices using the I2C interface.

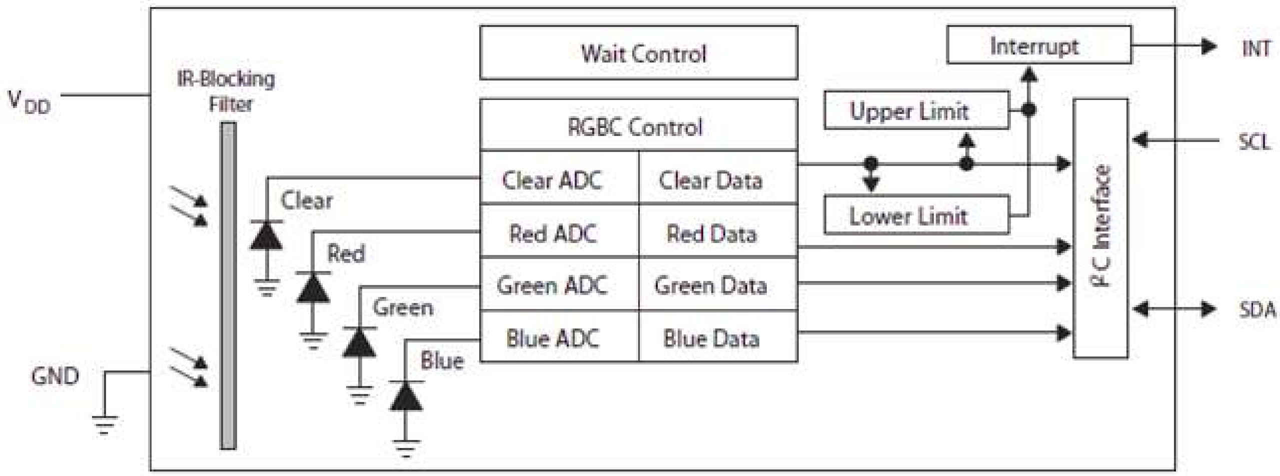

Fig 3.4: sensor working [15]

3.4 SET UP AND SAMPLES USED

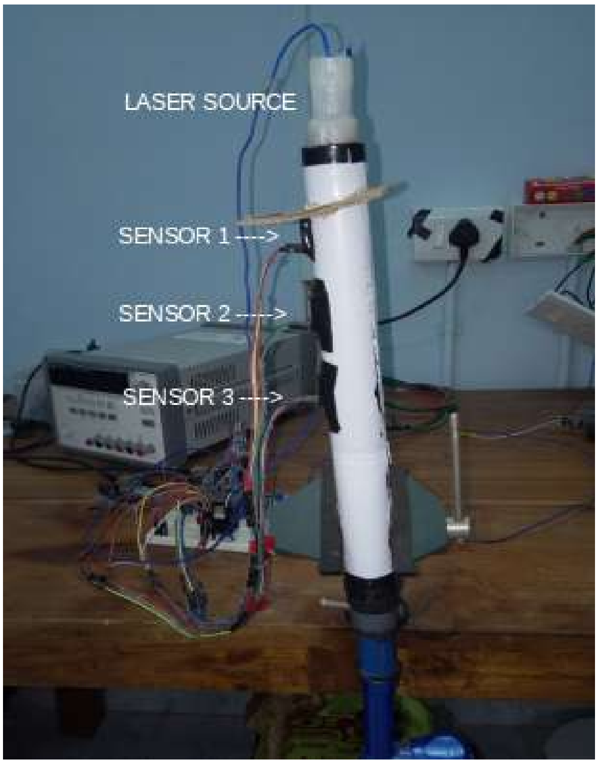

Fig 3.5: system prototype

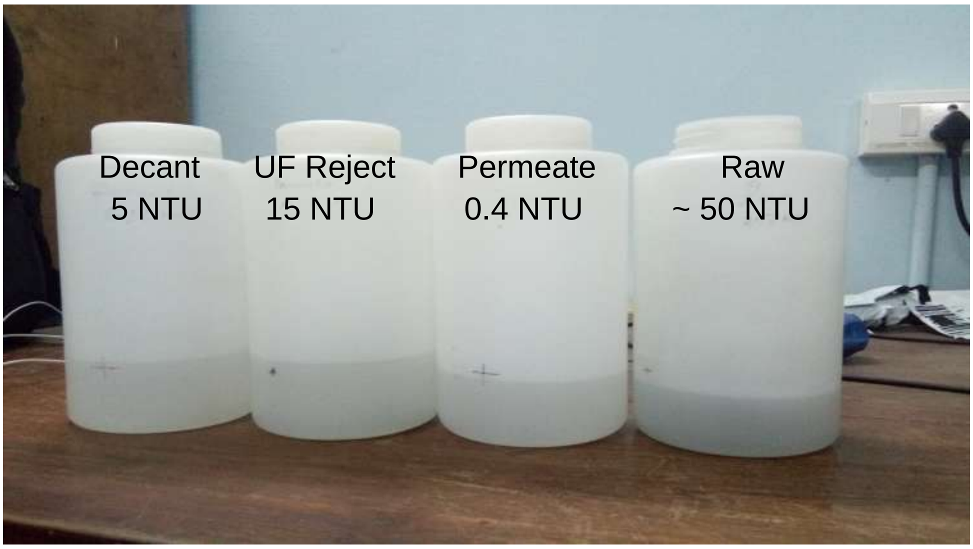

Fig 3.6: samples for testing

CHAPTER 4

RESULTS

4.1 OUTPUT AVERAGE

Output: Because of the laser light source, the measurements received are very sensitive to small changes in turbidity and thus the output of the sensor is needed to be averaged to develop a smooth turbidity signal. Instantaneous readings may vary considerably as particle density changes or large particles move. We implement a moving average of the past twenty readings in order to stabilize the output signal. Finally, the microcontroller performs all the necessary calculations-initializations and displays the resulting signal to the LCD display.

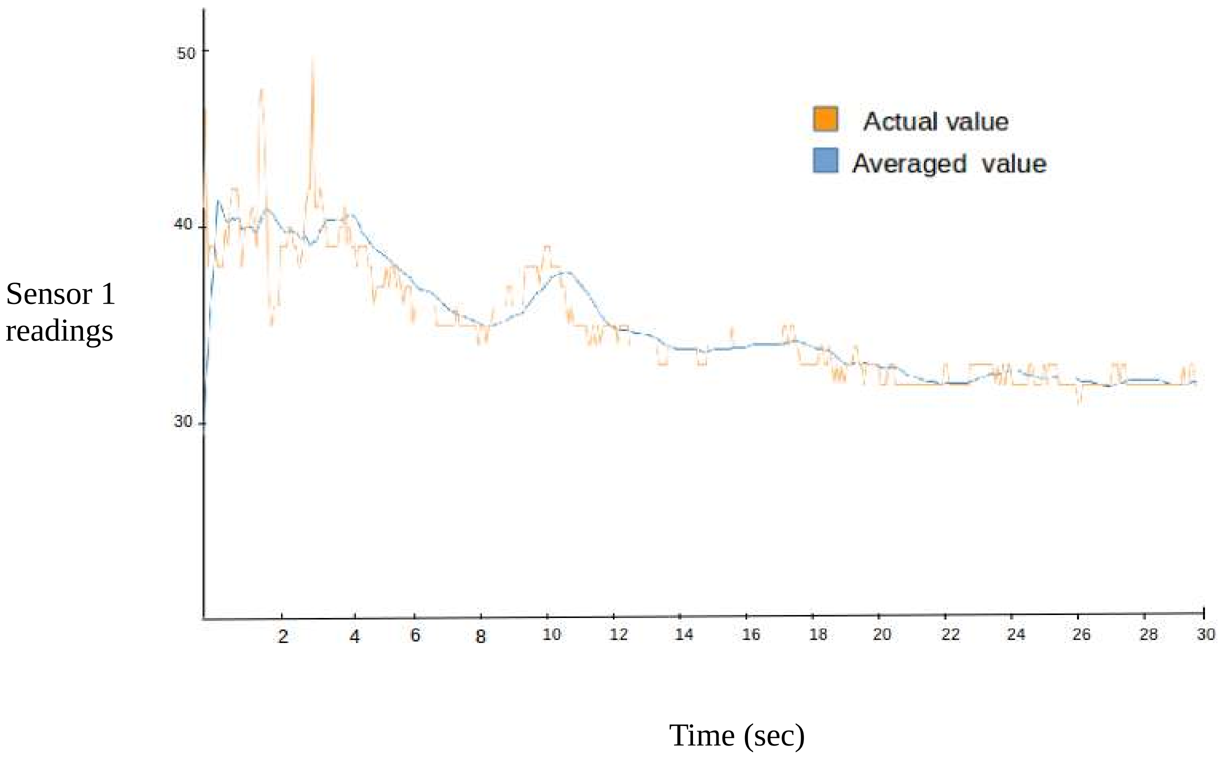

Fig 4.1 : graph of the actual output and averaged output

4.2 SENSOR DATA FOR A FIXED VOLTAGE

Output readings of sensor with the laser source voltage fixed at 2.90V.

Sensor output is a 16 bit digital output . Readings are on the scale of 0 — 65536.

SAMPLE	Sensor	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
No sample	Sen.1 Sen.2 Sen.3	41 33 33	42 33 30	43 38 33	44 32 27	41 32 21	40 35 20	39 33 27

Table 4.1: Range of Sensor outputs when there is no water sample

SAMPLE	Sensor	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Permeate 0.42 NTU	Sen.1 Sen.2 Sen.3	8-9 15-17 20	10-11 17 21	8 18-19 26	11 21 25	8 17 20	10-11 18 23	7 19 21

Table 4.2: Range of Sensor outputs for permeate sample

SAMPLE	Sensor	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Decant ~5.59 NTU	Sen.1 Sen.2 Sen.3	26-34 55-64 68-75	30-38 58-64 71-78	30-38 57-64 71-83	30-37 57-64 73-83	25-33 56-64 73-83	25-35 56-64 67-76	28-43 57-65 68-73

Table 4.3: Range of Sensor outputs for decant sample

SAMPLE	Sensor	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
UF Reject ~15 NTU	Sen.1 Sen.2 Sen.3	60-66 109-118 121-130	55-66 108-114 115-123	53-63 105-112 112-116	54-68 108-118 115-125	56-66 110-118 113-120	55-65 110-116 118-124	55-63 108-115 114-119

Table 4.4: Range of Sensor outputs for UF reject sample

SAMPLE	Sensor	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Raw ~50 NTU	Sen.1 Sen.2 Sen.3	140-150 219-223 140-142	135-154 219-223 140-142	145-160 221-227 141-146	145-164 224-228 140-144	150-167 218-224 137-141

Table 4.5: Range of Sensor outputs for Raw sample

Depending upon the above observations the range of

Sensor 1 : 39 -- 44
Sensor 2 : 32 -- 38 is taken for when there is no water sample
Sensor 3 : 20 -- 33

Sensor 1 : 8 -- 11
Sensor 2 : 16 -- 20 is taken for Permeate sample
Sensor 3 : 21 -- 26

Sensor 1 : 25 -- 45
Sensor 2 : 55 -- 70 is taken for Decant sample
Sensor 3 : 67 -- 83

Sensor 1 : 53 -- 68
Sensor 2 : 105 -- 116 is taken for UF Reject sample
Sensor 3 : 112 -- 125

Sensor 1 : 135 -- 167
Sensor 2 : 219 -- 228 is taken for Raw sample
Sensor 3 : 137 -- 146

4.3 EFFECT OF TEMPERATURE ON LASER INTENSITY

It is known that of Semiconductor Laser Diode wavelengths are inherently unstable, where for every 3 degrees' change, the wavelength of the of Semiconductor Laser Diode can change nearly 1nm[16]. If operated in constant current mode, diode output power tends to decrease as temperature increases and diode power can exceed its maximum rating with a decrease in temperature. The changes in temperature will translate into changes in wavelength and optical power of Semiconductor Laser Diode[16]. For this reason, choosing the constant power control mode of operation is recommended. If not, the temperature of operation will affect seriously the characteristics of of Semiconductor Laser Diode. While the temperature increases, the ratio between the electrical power and the optical power decreases. The temperature also depends on the emitted wavelength or the device operating life. It is important to discuss on an examination of performance of Semiconductor Laser Diode on a temperature variation because by theoretical study, laser thresholds are depends on temperature[16].

In some studies it has been reported that the change of temperature causes the wavelength changes linearly. It is proven that the increase in temperature causes a shift in the peak wavelength toward the long wavelength laser typical of 0.094 nm/°C[13]. In addition to the shift in wavelength, it is also shown that the increase in temperature causes a decrease in the optical power at the laser output[17].

Most laser systems exhibit variations of the light intensity over time. There are short term fluctuations due to the laser source stability and/or a thermal drift[18]. These modulations are of the time scale of minutes or hours. Additionally, the laser power drops in the course of the laser lifetime by up to 20%. Both types of fluctuations might cause a lowered throughput due to defective products or additional maintenance times.
Hence there is a need to make the measurements of the samples to be independent of variations in laser light intensity due to any reasons.

4.3.1 SENSOR DATA FOR A VARIED VOLTAGE

Observations when the supply of laser was varied from 2.80V to 3.00V

SAMPLE	Sensor 1 : Sensor 3	Sensor 2 : Sensor 3	Sensor 1 : Sensor 2
No Water	1.2 - 2.1	1 - 1.5	1.0 - 1.3
Permeate	0.2 - 0.4	0.7 - 0.8	0.3 - 0.5
UF Reject	0.42 - 0.51	0.83 - 1.00	0.44 - 0.53
Raw	0.96 - 1.25	1.54 - 1.6	0.6 - 0.79

Table 4.6: Range of Sensors' ratio output for samples

The above are the range of values for sensor ratios for different samples.
So for the model to identify the above samples under varying laser light conditions,

SENSOR 1: SENSOR 2 --------> 1 — 1.3 can be taken for a no sample situation.

SENSOR 1: SENSOR 3 --------> 0.2 — 0.4 can be taken for Permeate sample.

SENSOR 1: SENSOR 3 ---------> 0.41 — 0.52 can be taken for UF Reject sample .

SENSOR 1: SENSOR 2 --------> 0.6 — 0.79 can be taken for a Raw sample .

4.4 Interferences in Nephelometry

Nephelometry is based on measuring light intensity. Several factors can interfere with the measurements[4]. Interferences and their expected effect on output measurement.

Interference	Effect on the measurement	Direction of effect on the measurement
Stray light	Increases apparent light scatter	positive
Bubbles from entrained gases	Increases apparent light scatter	positive
Contamination of calibrants	Increases apparent light scatter	positive
Optical sensor fouling or scratching	Particularly with dynamic instruments. a) Possible beam blockage b) Possible scratches on optical surfaces	a) Negative b) Positive
Bubbles	Increases apparent light scatter	positive
Scratches	Increases apparent light scatter	positive

Table 4.7: interferences and effect on output

4.5 READINGS AND OUTPUT ON LCD

Sample : Raw.

COM5 (Arduino/Genuino Uno)

```
SENSOR: 1      ----------------------> Average of Sensor 1 is...155.00
SENSOR: 2      ----------------> Average of Sensor 2 is...208.30
SENSOR: 3R: 144        -------> Average of Sensor 3 is...143.90

SENSOR: 1      ----------------------> Average of Sensor 1 is...154.70
SENSOR: 2      ----------------> Average of Sensor 2 is...208.25
SENSOR: 3R: 145        -------> Average of Sensor 3 is...143.95

SENSOR: 1      ----------------------> Average of Sensor 1 is...153.85
SENSOR: 2      ----------------> Average of Sensor 2 is...208.05
SENSOR: 3R: 145        -------> Average of Sensor 3 is...144.00

SENSOR: 1      ----------------------> Average of Sensor 1 is...153.15
SENSOR: 2      ----------------> Average of Sensor 2 is...208.00
SENSOR: 3R: 146        -------> Average of Sensor 3 is...144.10

SENSOR: 1      ----------------------> Average of Sensor 1 is...152.40
SENSOR: 2      ----------------> Average of Sensor 2 is...208.10
SENSOR: 3R: 147        -------> Average of Sensor 3 is...144.25

SENSOR: 1      ----------------------> Average of Sensor 1 is...151.80
SENSOR: 2      ----------------> Average of Sensor 2 is...208.10
SENSOR: 3R: 147        -------> Average of Sensor 3 is...144.35
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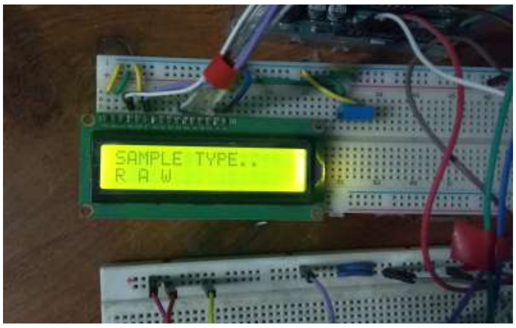

Fig 4.2: Monitor and LCD output for RAW sample

Sample : UF Reject.

COM5 (Arduino/Genuino Uno)

```
SENSOR: 1      ----------------------> Average of Sensor 1 is...45.70
SENSOR: 2      ----------------> Average of Sensor 2 is...100.15
SENSOR: 3      -------> Average of Sensor 3 is...112.60

SENSOR: 1      ----------------------> Average of Sensor 1 is...45.70
SENSOR: 2      ----------------> Average of Sensor 2 is...99.85
SENSOR: 3      -------> Average of Sensor 3 is...112.10

SENSOR: 1      ----------------------> Average of Sensor 1 is...45.55
SENSOR: 2      ----------------> Average of Sensor 2 is...99.35
SENSOR: 3      -------> Average of Sensor 3 is...111.70

SENSOR: 1      ----------------------> Average of Sensor 1 is...45.35
SENSOR: 2      ----------------> Average of Sensor 2 is...99.10
SENSOR: 3      -------> Average of Sensor 3 is...111.40

SENSOR: 1      ----------------------> Average of Sensor 1 is...45.00
SENSOR: 2      ----------------> Average of Sensor 2 is...98.50
SENSOR: 3      -------> Average of Sensor 3 is...111.15

SENSOR: 1      ----------------------> Average of Sensor 1 is...44.70
```

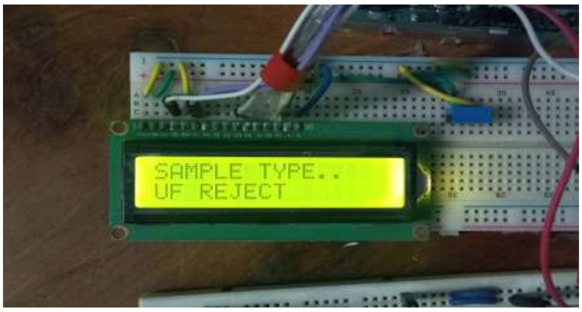

Fig 4.3: Monitor and LCD output for UF Reject sample

Sample : No water.

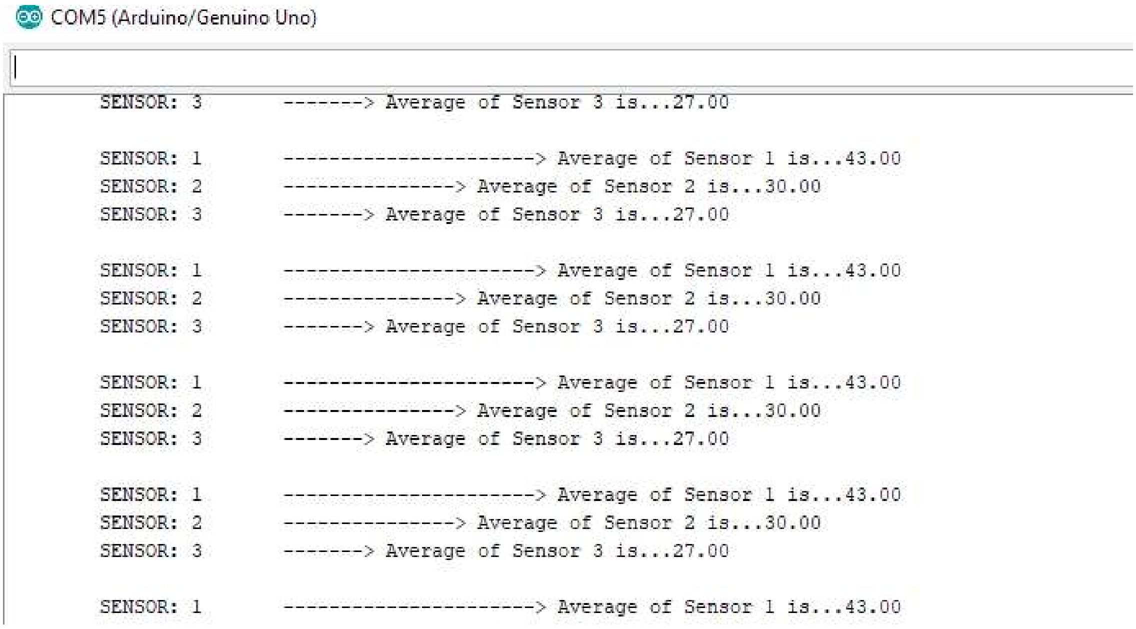

Fig 4.4: Monitor and LCD output for no sample

Sample : Decant.

COM5 (Arduino/Genuino Uno)

```
SENSOR: 3R: 77  -------> Average of Sensor 3 is...79.35

SENSOR: 1       ----------------------> Average of Sensor 1 is...29.65
SENSOR: 2       ---------------> Average of Sensor 2 is...55.60
SENSOR: 3R: 77  -------> Average of Sensor 3 is...79.05

SENSOR: 1       ----------------------> Average of Sensor 1 is...29.35
SENSOR: 2       ---------------> Average of Sensor 2 is...55.80
SENSOR: 3R: 79  -------> Average of Sensor 3 is...76.90

SENSOR: 1       ----------------------> Average of Sensor 1 is...28.45
SENSOR: 2       ---------------> Average of Sensor 2 is...55.85
SENSOR: 3R: 76  -------> Average of Sensor 3 is...76.30

SENSOR: 1       ----------------------> Average of Sensor 1 is...27.60
SENSOR: 2       ---------------> Average of Sensor 2 is...56.00
SENSOR: 3R: 71  -------> Average of Sensor 3 is...74.65

SENSOR: 1       ----------------------> Average of Sensor 1 is...26.95
SENSOR: 2       ---------------> Average of Sensor 2 is...56.15
SENSOR: 3R: 75  -------> Average of Sensor 3 is...74.05
```

Fig 4.5: Monitor and LCD output for decant sample

Sample : Permeate

COM5 (Arduino/Genuino Uno)

```
SENSOR: 3       -------> Average of Sensor 3 is...17.20
----------------------> Average of Sensor 1 is...6.05
SENSOR: 2       ---------------> Average of Sensor 2 is...18.00
SENSOR: 3       -------> Average of Sensor 3 is...17.90
----------------------> Average of Sensor 1 is...6.00
SENSOR: 2       ---------------> Average of Sensor 2 is...18.40
SENSOR: 3       -------> Average of Sensor 3 is...18.25
----------------------> Average of Sensor 1 is...5.95
SENSOR: 2       ---------------> Average of Sensor 2 is...19.00
SENSOR: 3       -------> Average of Sensor 3 is...18.35
----------------------> Average of Sensor 1 is...5.85
SENSOR: 2       ---------------> Average of Sensor 2 is...19.35
SENSOR: 3       -------> Average of Sensor 3 is...18.30
----------------------> Average of Sensor 1 is...5.75
SENSOR: 2       ---------------> Average of Sensor 2 is...19.40
SENSOR: 3       -------> Average of Sensor 3 is...18.25
----------------------> Average of Sensor 1 is...5.65
SENSOR: 2       ---------------> Average of Sensor 2 is...19.50
SENSOR: 3       -------> Average of Sensor 3 is...18.30
----------------------> Average of Sensor 1 is...5.60
SENSOR: 2       ---------------> Average of Sensor 2 is...19.55
```

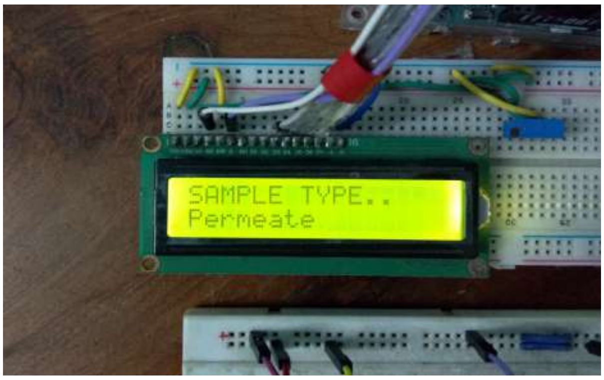

Fig 4.6: Monitor and LCD output for Permeate sample

4.6. CALIBRATING THE SENSOR OUTPUTS FROM NEPHELOMETRIC METHOD TO DETERMINE TURBIDITY OF A SAMPLE.

Samples used for calibration purposes is made using kaolin clay powder.

(Readings taken here are the values that are most repeatable during observation)

The turbidity of the below samples was measured using a commercial turbidity meter[20].

SAMPLE 1: 0.42 NTU

		Trial 1	Trial 2	Trial 3
0.42 NTU	Sensor 1 Sensor 2 Sensor 3	8 17 20	10 25 26	8 19 21

SAMPLE 2: 2.42NTU

		Trial 1	Trial 2	Trial 3
2.42 NTU	Sensor 1 Sensor 2 Sensor 3	11 19 23	13 20 22	11 19 23

SAMPLE 3: 5.59 NTU

		Trial 1	Trial 2	Trial 3
5.59 NTU	Sensor 1 Sensor 2 Sensor 3	23 56 70	28 57 68	35 72 86

SAMPLE 4: 18.5 NTU

		Trial 1	Trial 2	Trial 3
18.5 NTU	Sensor 1 Sensor 2 Sensor 3	78 162 184	77 172 194	76 167 190

SAMPLE 5: 19.6 NTU

		Trial 1	Trial 2	Trial 3
19.6 NTU	Sensor 1 Sensor 2 Sensor 3	77 162 186	76 168 187	81 170 164

SAMPLE 6: 28.4 NTU

		Trial 1	Trial 2	Trial 3
28.4 NTU	Sensor 1 Sensor 2 Sensor 3	109 218 213	110 226 218	104 229 216

SAMPLE 7: 38 NTU

		Trial 1	Trial 2	Trial 3
38 NTU	Sensor 1 Sensor 2 Sensor 3	146 283 261	149 285 262	147 270 256

SAMPLE 8: 58.7 NTU

		Trial 1	Trial 2	Trial 3
58.7 NTU	Sensor 1 Sensor 2 Sensor 3	223 357 281	222 359 281	225 359 280

SAMPLE 9: 86.4 NTU

		Trial 1	Trial 2	Trial 3
86.4 NTU	Sensor 1 Sensor 2 Sensor 3	279 414 285	267 414 291	281 434 295

SAMPLE 10: 93.4 NTU

		Trial 1	Trial 2	Trial 3
93.4 NTU	Sensor 1	312	305	314
	Sensor 2	414	420	417
	Sensor 3	284	287	290

SAMPLE 11: 112 NTU

		Trial 1	Trial 2	Trial 3
112 NTU	Sensor 1	335	328	333
	Sensor 2	446	430	445
	Sensor 3	289	290	290

SAMPLE 12: 172 NTU

		Trial 1	Trial 2	Trial 3
172 NTU	Sensor 1	370	362	365
	Sensor 2	495	496	477
	Sensor 3	293	298	298

Table 4.8: Sensor outputs for different turbidities

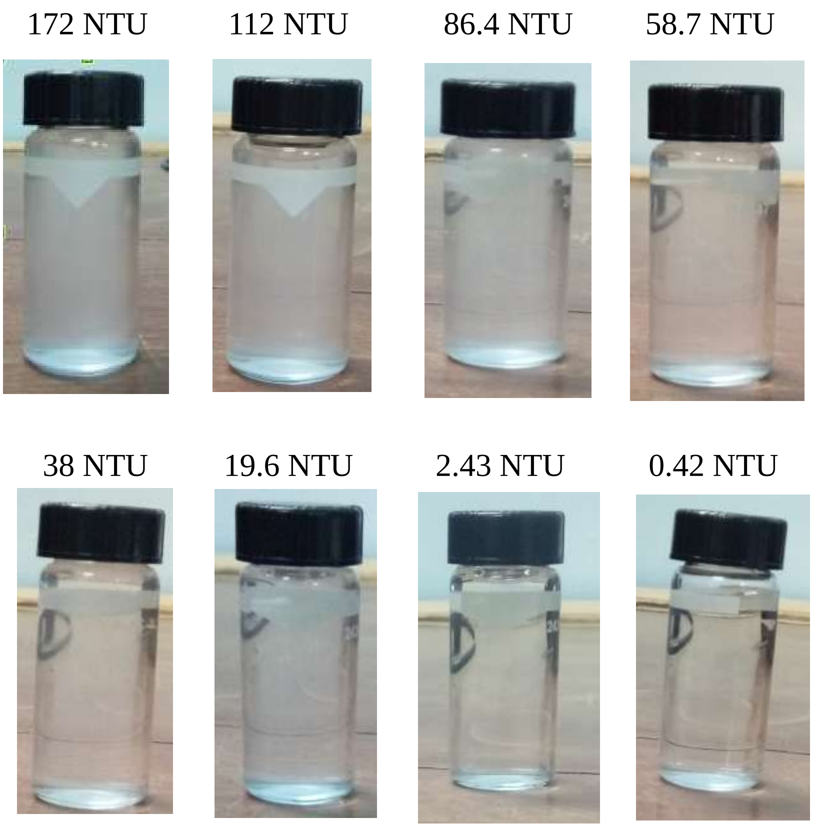

Fig 4.7: Samples used for calibration purpose

4.6.1 OUTPUT OF SENSOR FOR DIFFERENT TURBID SAMPLES

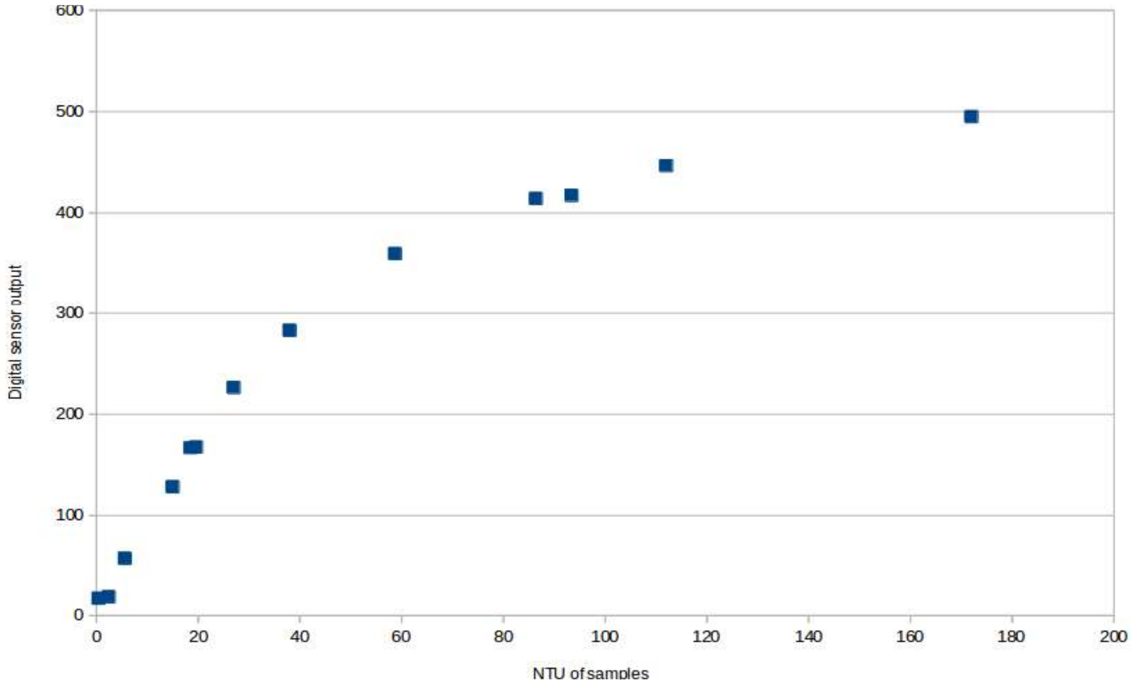

Fig 4.8: Graph of sensor 2 output vs NTU of the samples

The graph holds linearity for samples of NTU below 40 after which the linearity is lost.

.

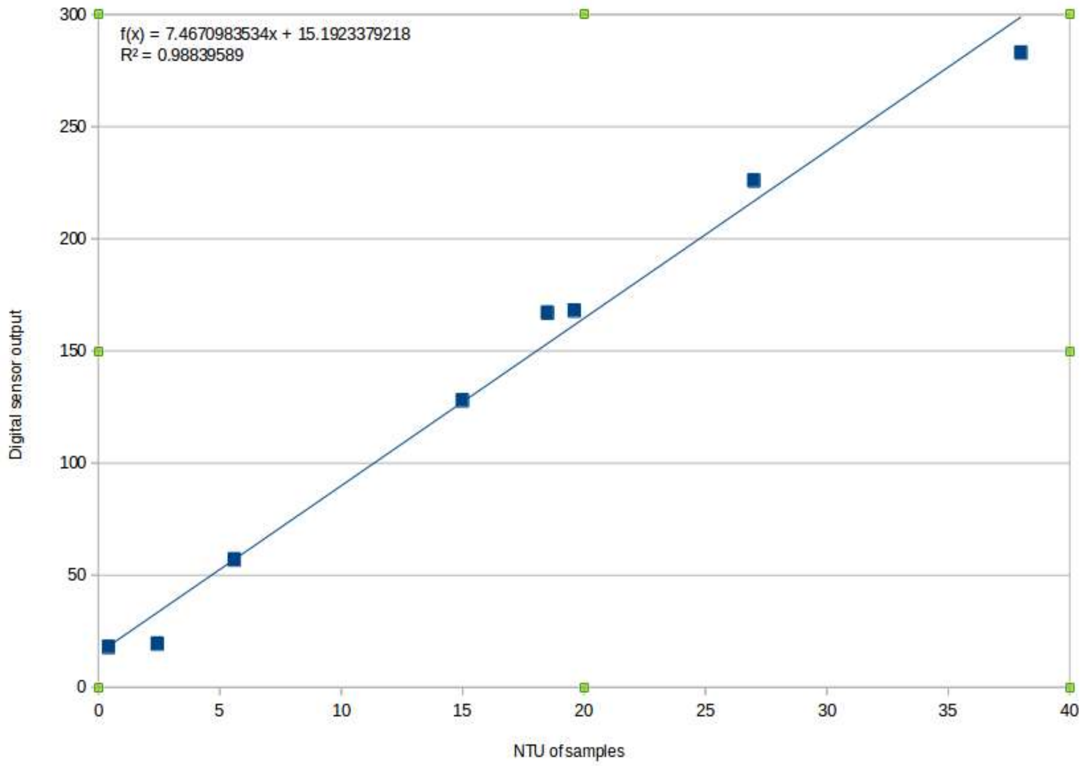

Fig 4.9: Graph of sensor 2 output vs NTU of the samples below 40 NTU

Considering the linear range of response of the system below 40 NTU,the sensor output is calibrated accordingly to the equation

$$T = 0.1339S - 2.0345$$

where T is the turbidity in NTU and S is the digital sensor output at 2.9V.

4.6.2 MONITOR OUTPUT FOR DIFFERENT TURBIDITIES

Output for a 0.42 NTU sample

```
COM5 (Arduino/Genuino Uno)

SENSOR: 2       ---------------> Average of Sensor 2 is...19.70       turbidity: 0.60
SENSOR: 2       ---------------> Average of Sensor 2 is...19.25       turbidity: 0.54
SENSOR: 2       ---------------> Average of Sensor 2 is...18.85       turbidity: 0.49
SENSOR: 2       ---------------> Average of Sensor 2 is...18.40       turbidity: 0.43
SENSOR: 2       ---------------> Average of Sensor 2 is...17.85       turbidity: 0.36
SENSOR: 2       ---------------> Average of Sensor 2 is...17.40       turbidity: 0.30
SENSOR: 2       ---------------> Average of Sensor 2 is...17.05       turbidity: 0.25
SENSOR: 2       ---------------> Average of Sensor 2 is...17.00       turbidity: 0.24
SENSOR: 2       ---------------> Average of Sensor 2 is...17.00       turbidity: 0.24
SENSOR: 2       ---------------> Average of Sensor 2 is...17.00       turbidity: 0.24
SENSOR: 2       ---------------> Average of Sensor 2 is...17.05       turbidity: 0.25
SENSOR: 2       ---------------> Average of Sensor 2 is...17.15       turbidity: 0.26
SENSOR: 2       ---------------> Average of Sensor 2 is...17.25       turbidity: 0.28
SENSOR: 2       ---------------> Average of Sensor 2 is...17.35       turbidity: 0.29
SENSOR: 2       ---------------> Average of Sensor 2 is...17.35       turbidity: 0.29
SENSOR: 2       ---------------> Average of Sensor 2 is...17.40       turbidity: 0.30
SENSOR: 2       ---------------> Average of Sensor 2 is...17.45       turbidity: 0.30
SENSOR: 2       ---------------> Average of Sensor 2 is...17.50       turbidity: 0.31
SENSOR: 2       ---------------> Average of Sensor 2 is...17.55       turbidity: 0.32
SENSOR: 2       ---------------> Average of Sensor 2 is...17.60       turbidity: 0.32
SENSOR: 2       ---------------> Average of Sensor 2 is...17.65       turbidity: 0.33
SENSOR: 2       ---------------> Average of Sensor 2 is...17.70       turbidity: 0.34
SENSOR: 2       ---------------> Average of Sensor 2 is...17.75       turbidity: 0.34
SENSOR: 2       ---------------> Average of Sensor 2 is...17.80       turbidity: 0.35
SENSOR: 2       ---------------> Average of Sensor 2 is...17.90       turbidity: 0.36
SENSOR: 2       ---------------> Average of Sensor 2 is...18.00       turbidity: 0.38
SENSOR: 2       ---------------> Average of Sensor 2 is...18.10       turbidity: 0.39
```

Fig 4.10: Serial monitor output for 0.42 NTU sample

Output for a 5.5 NTU sample

```
COM5 (Arduino/Genuino Uno)

SENSOR: 2       ---------------> Average of Sensor 2 is...67.15       turbidity: 6.96
SENSOR: 2       ---------------> Average of Sensor 2 is...67.30       turbidity: 6.98
SENSOR: 2       ---------------> Average of Sensor 2 is...67.55       turbidity: 7.01
SENSOR: 2       ---------------> Average of Sensor 2 is...67.45       turbidity: 7.00
SENSOR: 2       ---------------> Average of Sensor 2 is...67.05       turbidity: 6.94
SENSOR: 2       ---------------> Average of Sensor 2 is...67.10       turbidity: 6.95
SENSOR: 2       ---------------> Average of Sensor 2 is...66.95       turbidity: 6.93
SENSOR: 2       ---------------> Average of Sensor 2 is...66.90       turbidity: 6.92
SENSOR: 2       ---------------> Average of Sensor 2 is...66.65       turbidity: 6.89
SENSOR: 2       ---------------> Average of Sensor 2 is...66.20       turbidity: 6.83
SENSOR: 2       ---------------> Average of Sensor 2 is...65.75       turbidity: 6.77
SENSOR: 2       ---------------> Average of Sensor 2 is...65.40       turbidity: 6.72
SENSOR: 2       ---------------> Average of Sensor 2 is...65.05       turbidity: 6.68
SENSOR: 2       ---------------> Average of Sensor 2 is...64.70       turbidity: 6.63
SENSOR: 2       ---------------> Average of Sensor 2 is...64.25       turbidity: 6.57
SENSOR: 2       ---------------> Average of Sensor 2 is...63.70       turbidity: 6.49
SENSOR: 2       ---------------> Average of Sensor 2 is...63.15       turbidity: 6.42
SENSOR: 2       ---------------> Average of Sensor 2 is...62.70       turbidity: 6.36
SENSOR: 2       ---------------> Average of Sensor 2 is...62.25       turbidity: 6.30
SENSOR: 2       ---------------> Average of Sensor 2 is...61.85       turbidity: 6.25
SENSOR: 2       ---------------> Average of Sensor 2 is...61.50       turbidity: 6.20
SENSOR: 2       ---------------> Average of Sensor 2 is...61.10       turbidity: 6.15
SENSOR: 2       ---------------> Average of Sensor 2 is...60.70       turbidity: 6.09
SENSOR: 2       ---------------> Average of Sensor 2 is...60.45       turbidity: 6.06
SENSOR: 2       ---------------> Average of Sensor 2 is...60.45       turbidity: 6.06
```

Fig 4.11: Serial monitor output for 5.5 NTU sample

Output for a 15.2 NTU sample

COM5 (Arduino/Genuino Uno)

```
SENSOR: 2        ---------------> Average of Sensor 2 is...115.25        turbidity: 13.40
SENSOR: 2        ---------------> Average of Sensor 2 is...114.95        turbidity: 13.36
SENSOR: 2        ---------------> Average of Sensor 2 is...115.15        turbidity: 13.38
SENSOR: 2        ---------------> Average of Sensor 2 is...115.85        turbidity: 13.48
SENSOR: 2        ---------------> Average of Sensor 2 is...116.30        turbidity: 13.54
SENSOR: 2        ---------------> Average of Sensor 2 is...116.65        turbidity: 13.58
SENSOR: 2        ---------------> Average of Sensor 2 is...117.05        turbidity: 13.64
SENSOR: 2        ---------------> Average of Sensor 2 is...117.40        turbidity: 13.69
SENSOR: 2        ---------------> Average of Sensor 2 is...117.70        turbidity: 13.73
SENSOR: 2        ---------------> Average of Sensor 2 is...117.95        turbidity: 13.76
SENSOR: 2        ---------------> Average of Sensor 2 is...118.15        turbidity: 13.79
SENSOR: 2        ---------------> Average of Sensor 2 is...118.25        turbidity: 13.80
SENSOR: 2        ---------------> Average of Sensor 2 is...118.35        turbidity: 13.81
SENSOR: 2        ---------------> Average of Sensor 2 is...118.45        turbidity: 13.83
SENSOR: 2        ---------------> Average of Sensor 2 is...118.55        turbidity: 13.84
SENSOR: 2        ---------------> Average of Sensor 2 is...118.20        turbidity: 13.79
SENSOR: 2        ---------------> Average of Sensor 2 is...118.05        turbidity: 13.77
SENSOR: 2        ---------------> Average of Sensor 2 is...117.70        turbidity: 13.73
SENSOR: 2        ---------------> Average of Sensor 2 is...117.50        turbidity: 13.70
SENSOR: 2        ---------------> Average of Sensor 2 is...117.35        turbidity: 13.68
SENSOR: 2        ---------------> Average of Sensor 2 is...117.60        turbidity: 13.71
SENSOR: 2        ---------------> Average of Sensor 2 is...117.65        turbidity: 13.72
SENSOR: 2        ---------------> Average of Sensor 2 is...117.40        turbidity: 13.69
SENSOR: 2        ---------------> Average of Sensor 2 is...116.85        turbidity: 13.61
SENSOR: 2        ---------------> Average of Sensor 2 is...116.80        turbidity: 13.61
SENSOR: 2        ---------------> Average of Sensor 2 is...116.85        turbidity: 13.61
SENSOR: 2        ---------------> Average of Sensor 2 is...116.75        turbidity: 13.60
```

Fig 4.12: Serial monitor output for 15.2 NTU sample

Output for a 30.1 NTU sample

COM5 (Arduino/Genuino Uno)

```
SENSOR: 2        ---------------> Average of Sensor 2 is...232.20        turbidity: 29.06
SENSOR: 2        ---------------> Average of Sensor 2 is...232.20        turbidity: 29.06
SENSOR: 2        ---------------> Average of Sensor 2 is...232.25        turbidity: 29.06
SENSOR: 2        ---------------> Average of Sensor 2 is...232.25        turbidity: 29.06
SENSOR: 2        ---------------> Average of Sensor 2 is...232.15        turbidity: 29.05
SENSOR: 2        ---------------> Average of Sensor 2 is...232.20        turbidity: 29.06
SENSOR: 2        ---------------> Average of Sensor 2 is...232.30        turbidity: 29.07
SENSOR: 2        ---------------> Average of Sensor 2 is...232.30        turbidity: 29.07
SENSOR: 2        ---------------> Average of Sensor 2 is...232.25        turbidity: 29.06
SENSOR: 2        ---------------> Average of Sensor 2 is...232.30        turbidity: 29.07
SENSOR: 2        ---------------> Average of Sensor 2 is...232.35        turbidity: 29.08
SENSOR: 2        ---------------> Average of Sensor 2 is...232.50        turbidity: 29.10
SENSOR: 2        ---------------> Average of Sensor 2 is...232.65        turbidity: 29.12
SENSOR: 2        ---------------> Average of Sensor 2 is...232.70        turbidity: 29.12
SENSOR: 2        ---------------> Average of Sensor 2 is...232.75        turbidity: 29.13
SENSOR: 2        ---------------> Average of Sensor 2 is...232.85        turbidity: 29.14
SENSOR: 2        ---------------> Average of Sensor 2 is...232.85        turbidity: 29.14
SENSOR: 2        ---------------> Average of Sensor 2 is...232.90        turbidity: 29.15
SENSOR: 2        ---------------> Average of Sensor 2 is...233.00        turbidity: 29.16
SENSOR: 2        ---------------> Average of Sensor 2 is...233.10        turbidity: 29.18
SENSOR: 2        ---------------> Average of Sensor 2 is...233.20        turbidity: 29.19
SENSOR: 2        ---------------> Average of Sensor 2 is...233.20        turbidity: 29.19
SENSOR: 2        ---------------> Average of Sensor 2 is...233.25        turbidity: 29.20
SENSOR: 2        ---------------> Average of Sensor 2 is...233.30        turbidity: 29.20
SENSOR: 2        ---------------> Average of Sensor 2 is...233.35        turbidity: 29.21
```

Fig 4.13: Serial monitor output for 30.1 NTU sample

CHAPTER 5

CONCLUSION

The samples using the nephelometric method were succesfully distinguished into different classes and the turbidity of the samples were predicted. The device is of low cost and easy to use. The construction materials are easily obtainable. This system can be used as a part of a low cost sensor network to provide water quality information to consumers. If installed at the consumer end will provide water quality information to the user both at industrial and household levels. Data collected can be put up on a website for security.

Further, the model can be made to transmit the readings to a remote server so that the user can have access to them from anywhere and anytime. It would be extremely useful, if a real-time turbidity monitoring system could be installed to act as a type of "early warning system" for possible potable water quality deterioration at homes. For such a system to be implementable though, turbidity systems that are cheap, easy to install and use, and could have capabilities of sending information, wire-lessly, to a central data logging and processing facility would be essential. Apart from considering turbidity alone as parameter to assess the water quality,alongside various other parameters like pH,electrical conductivity,dissolved oxygen etc can also be included. The system could be further developed to analyze the biological as well as chemical data of the sample.

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APPENDIX

C code for programming Arduino Uno Microcontroller

(i) code for making the system insensitive to changes in laser intensity.

```
#include <Wire.h>
#include "Adafruit_TCS34725.h"
#define TCAADDR 0x70
#include<LiquidCrystal.h>
LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
Adafruit_TCS34725 tcs_1 = Adafruit_TCS34725(TCS34725_INTEGRATIONTIME_101MS,
TCS34725_GAIN_60X);
Adafruit_TCS34725 tcs_2 = Adafruit_TCS34725(TCS34725_INTEGRATIONTIME_101MS,
TCS34725_GAIN_60X);
Adafruit_TCS34725 tcs_3 = Adafruit_TCS34725(TCS34725_INTEGRATIONTIME_101MS,
TCS34725_GAIN_60X);
uint16_t red_1, green_1, blue_1, clear_1;
uint16_t red_2, green_2, blue_2, clear_2;
uint16_t red_3, green_3, blue_3, clear_3;

const int TotalRead = 20;

int red_value1[TotalRead];
int red_value2[TotalRead];
int red_value3[TotalRead];

int ArrIndex = 0;

float total_1 = 0, total_2 = 0, total_3 = 0;

float average_1=0, average_2=0, average_3=0;

void tcaselect(uint16_t i)
 {
  if (i > 7) return;

  Wire.beginTransmission(TCAADDR);
  Wire.write(1 << i);
  Wire.endTransmission();
 }

void setup()
 {
  Serial.begin(9600);
  lcd.begin(16,2);
```



```
    tcaselect(1);
```

```
        if(tcs_1.begin())
            {
              Serial.println(" DETECTED FIRST SENSOR");
            }
        if(!tcs_1.begin())
           {
            Serial.println("sensor1 not found");
            }

      tcaselect(2);
       if(tcs_2.begin())
            {
               Serial.println(" DETECTED SECOND SENSOR");
            }
       else {Serial.println("sensor2 not found");
           }

     tcaselect(3);
       if(!tcs_3.begin())
           {
            Serial.println("sensor3 not found");
           }
       if(tcs_3.begin())
           {
            Serial.println(" DETECTED THIRD SENSOR");
           }


  for(int i =0; i<TotalRead ; i++){
                               red_value1[i] = 0;
                               red_value2[i] = 0;
                               red_value3[i] = 0;
                              }

 }


void loop()
{

   tcaselect(1);
   tcs_1.getRawData(&red_1, &green_1, &blue_1, &clear_1);

   tcaselect(2);
   tcs_2.getRawData(&red_2, &green_2, &blue_2, &clear_2);

   tcaselect(3);
   tcs_3.getRawData(&red_3, &green_3, &blue_3, &clear_3);

   total_1 = total_1 -  red_value1[ArrIndex];
   total_2 = total_2 -  red_value2[ArrIndex];
   total_3 = total_3 -  red_value3[ArrIndex];

   red_value1[ArrIndex] = red_1;
   red_value2[ArrIndex] = red_2;
```



```
   red_value3[ArrIndex] = red_3;
```

```
   total_1 = total_1 +  red_value1[ArrIndex];
   total_2 = total_2 +  red_value2[ArrIndex];
   total_3 = total_3 +  red_value3[ArrIndex];

   ArrIndex++;

   if(ArrIndex >= TotalRead){
   ArrIndex =0;
    }

  average_1 = total_1/TotalRead;
  average_2 = total_2/TotalRead;
  average_3 = total_3/TotalRead;

  float ratio12 = average_1/average_2;
  float ratio13 = average_1/average_3;
  float ratio23 = average_2/average_3;
  float t =0.1339*(average_2) – 2.0345;

  if((ratio12>=1.0 && ratio12<=1.3)){
   lcd.clear();
   lcd.setCursor(2,0);
   lcd.print("ADD WATER!!!");

  }
 else if((ratio13>=0.2 && ratio13<=0.4) )
 {
   lcd.clear();
   lcd.setCursor(0,0);
   lcd.print("SAMPLE TYPE..");
   lcd.setCursor(0,1);
   lcd.print("Permeate");


 }

/*else if(/*(average_2 >= 13.00 && average_2 <= 15.00) && (ratio23>=0.80 &&
ratio23<=1.10)/*(average_2 >= 13.00 && average_2 <=15.00)&& (average_3 >= 13.00 && average_3 <=
15.00))*/
/* {
   lcd.clear();
   lcd.setCursor(0,0);
   lcd.print("SAMPLE TYPE..");
   lcd.setCursor(0,1);
   lcd.print("DECANT");
 }*/

  else if((ratio13>=0.41 && ratio13<=0.52))
 {
   lcd.clear();
   lcd.setCursor(0,0);
   lcd.print("SAMPLE TYPE..");
   lcd.setCursor(0,1);
   lcd.print("UF REJECT ");
```



```
 }
```

```
 else if((ratio12>=0.6 && ratio12<=0.8))
  {
    lcd.clear();
    lcd.setCursor(0,0);
    lcd.print("SAMPLE TYPE..");
    lcd.setCursor(0,1);
    lcd.print("R A W");
  }


     Serial.println("\n\tSENSOR: 1");
     Serial.print("R: "); Serial.print(red_1); Serial.print(" ");
    // Serial.print("\tG: "); Serial.print(green_1); Serial.print(" ");
    // Serial.print("\tB: "); Serial.print(blue_1); Serial.print(" ");
     //Serial.print("\tC: "); Serial.print(clear_1); Serial.print(" ");
    // Serial.print("\t-------> Average of Sensor 1 is..."); Serial.print(average_1);

     Serial.print("\n\tSENSOR: 2");
     Serial.print("R: "); Serial.print(red_2); Serial.print(" ");
   /*  Serial.print("\tG: "); Serial.print(green_2); Serial.print(" ");
     Serial.print("\tB: "); Serial.print(blue_2); Serial.print(" ");
     Serial.print("\tC: "); Serial.print(clear_2); Serial.print(" ");*/
    // Serial.print("\t-------> Average of Sensor 2 is..."); Serial.print(average_2); Serial.print(" ");

     Serial.print("\n\tSENSOR: 3");
     Serial.print("R: "); Serial.print(red_3); Serial.print(" ");
    /* Serial.print("\tG: "); Serial.print(green_3); Serial.print(" ");
     Serial.print("\tB: "); Serial.print(blue_3); Serial.print(" ");
     Serial.print("\tC: "); Serial.print(clear_3); Serial.print(" "); */
    // Serial.print("\t-------> Average of Sensor 3 is..."); Serial.print(average_3); Serial.print(" ");
     Serial.print("\t\tSENSOR-1 : SENSOR-3 is.. ");Serial.print(ratio13);Serial.print(" ");
     Serial.print("\t\tSENSOR-2 : SENSOR-3 is.. ");Serial.print(ratio23);Serial.print(" ");
     Serial.print("\t\tSENSOR-1 : SENSOR-2 is.. ");Serial.print(ratio12);Serial.print(" ");
     delay(1);


}
```

****

SECOND CODE

(ii) code to differentiate between samples of different turbidities

```
#include <Wire.h>
#include "Adafruit_TCS34725.h"
#define TCAADDR 0x70
#include<LiquidCrystal.h>
LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
Adafruit_TCS34725 tcs_1 = Adafruit_TCS34725(TCS34725_INTEGRATIONTIME_101MS,
TCS34725_GAIN_60X);
```



```
Adafruit_TCS34725 tcs_2 = Adafruit_TCS34725(TCS34725_INTEGRATIONTIME_101MS,
```

```
 TCS34725_GAIN_60X);
Adafruit_TCS34725 tcs_3 = Adafruit_TCS34725(TCS34725_INTEGRATIONTIME_101MS,
TCS34725_GAIN_60X);
uint16_t red_1, green_1, blue_1, clear_1;
uint16_t red_2, green_2, blue_2, clear_2;
uint16_t red_3, green_3, blue_3, clear_3;

const int TotalRead = 20;

int red_value1[TotalRead];
int red_value2[TotalRead];
int red_value3[TotalRead];

int ArrIndex = 0;

float total_1 = 0, total_2 = 0, total_3 = 0;

float average_1=0, average_2=0, average_3=0;

void tcaselect(uint16_t i)
 {
  if (i > 7) return;

  Wire.beginTransmission(TCAADDR);
  Wire.write(1 << i);
  Wire.endTransmission();
 }

void setup()
 {
  Serial.begin(9600);
  lcd.begin(16,2);


        tcaselect(1);
         if(tcs_1.begin())
             {
               Serial.println(" DETECTED FIRST SENSOR");
             }
         if(!tcs_1.begin())
            {
             Serial.println("sensor1 not found");
             }

       tcaselect(2);
        if(tcs_2.begin())
             {
                Serial.println(" DETECTED SECOND SENSOR");
             }
        else {Serial.println("sensor2 not found");
            }

      tcaselect(3);
        if(!tcs_3.begin())
            {
```



```
             Serial.println("sensor3 not found");
```

```
            }
        if(tcs_3.begin())
            {
             Serial.println(" DETECTED THIRD SENSOR");
            }


  for(int i =0; i<TotalRead ; i++){
                                red_value1[i] = 0;
                                red_value2[i] = 0;
                                red_value3[i] = 0;
                               }

 }


void loop()
{

    tcaselect(1);
    tcs_1.getRawData(&red_1, &green_1, &blue_1, &clear_1);

    tcaselect(2);
    tcs_2.getRawData(&red_2, &green_2, &blue_2, &clear_2);

    tcaselect(3);
    tcs_3.getRawData(&red_3, &green_3, &blue_3, &clear_3);

    total_1 = total_1 -  red_value1[ArrIndex];
    total_2 = total_2 -  red_value2[ArrIndex];
    total_3 = total_3 -  red_value3[ArrIndex];

    red_value1[ArrIndex] = red_1;
    red_value2[ArrIndex] = red_2;
    red_value3[ArrIndex] = red_3;

    total_1 = total_1 +  red_value1[ArrIndex];
    total_2 = total_2 +  red_value2[ArrIndex];
    total_3 = total_3 +  red_value3[ArrIndex];

    ArrIndex++;

    if(ArrIndex >= TotalRead){
    ArrIndex =0;
     }

   average_1 = total_1/TotalRead;
   average_2 = total_2/TotalRead;
   average_3 = total_3/TotalRead;

   float ratio12 = average_1/average_2;
   float ratio13 = average_1/average_3;
   float ratio23 = average_2/average_3;
   float t =0.1339*(average_2) – 2.0345;
```



```
   else if((average_1>=39 && average_1<=44))
```

```
 {
   lcd.clear();
   lcd.setCursor(2,0);
   lcd.print("ADD WATER!!!");

  }
 else if((average_1>=8 && average_1<=11))
 {
   lcd.clear();
   lcd.setCursor(0,0);
   lcd.print("SAMPLE TYPE..");
   lcd.setCursor(0,1);
   lcd.print("Permeate");


 }

else if((average_1>=25 && average_1<=45))
 {
   lcd.clear();
   lcd.setCursor(0,0);
   lcd.print("SAMPLE TYPE..");
   lcd.setCursor(0,1);
   lcd.print("DECANT");
 }

 else if((average_1>=53 && average_1<=68))
 {
   lcd.clear();
   lcd.setCursor(0,0);
   lcd.print("SAMPLE TYPE..");
   lcd.setCursor(0,1);
   lcd.print("UF REJECT ");

 }
 else if((average_1>=135 && average_1<=167))
 {
   lcd.clear();
   lcd.setCursor(0,0);
   lcd.print("SAMPLE TYPE..");
   lcd.setCursor(0,1);
   lcd.print("R A W");
 }


    Serial.println("\n\tSENSOR: 1");
    Serial.print("R: "); Serial.print(red_1); Serial.print(" ");
   // Serial.print("\tG: "); Serial.print(green_1); Serial.print(" ");
   // Serial.print("\tB: "); Serial.print(blue_1); Serial.print(" ");
    //Serial.print("\tC: "); Serial.print(clear_1); Serial.print(" ");
   // Serial.print("\t-------> Average of Sensor 1 is..."); Serial.print(average_1);

    Serial.print("\n\tSENSOR: 2");
    Serial.print("R: "); Serial.print(red_2); Serial.print(" ");
  /*  Serial.print("\tG: "); Serial.print(green_2); Serial.print(" ");
```

```
    Serial.print("\tB: "); Serial.print(blue_2); Serial.print(" ");
```

```
    Serial.print("\tC: "); Serial.print(clear_2); Serial.print(" ");*/
    Serial.print("\t-------> Average of Sensor 2 is..."); Serial.print(average_2); Serial.print(" ");
    Serial.print("\tturbidity: "); Serial.print(t); Serial.print(" ");

    Serial.print("\n\tSENSOR: 3");
    Serial.print("R: "); Serial.print(red_3); Serial.print(" ");
   /* Serial.print("\tG: "); Serial.print(green_3); Serial.print(" ");
    Serial.print("\tB: "); Serial.print(blue_3); Serial.print(" ");
    Serial.print("\tC: "); Serial.print(clear_3); Serial.print(" "); */
   // Serial.print("\t-------> Average of Sensor 3 is..."); Serial.print(average_3); Serial.print(" ");
  /*  Serial.print("\t\tSENSOR-1 : SENSOR-3 is.. ");Serial.print(ratio13);Serial.print(" ");
    Serial.print("\t\tSENSOR-2 : SENSOR-3 is.. ");Serial.print(ratio23);Serial.print(" ");
    Serial.print("\t\tSENSOR-1 : SENSOR-2 is.. ");Serial.print(ratio12);Serial.print(" ");*/
    delay(1);


}
```