

Measuring Turbidity of Water Based Photo Voltaic Cell and Laser Light

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Abstract— this paper presents on the design and development of laser beam to measure turbidity of water and liquids. The method is done by applying laser beam on three samples (pure water, water with some milk and water with some juice), and measuring the residual of laser beam which penetrated through the sample. This penetrated beam was measured by a photo voltaic solar which received it and produced a very small voltage as an output proportional to the penetrated beam intensity. The produced voltage was read and calibrated to give NTU reading according to a sensor (photo voltaic solar) output is considered as an input to the control program. The controller which control and monitor the turbidity of selected samples was done by using Lab VIEW and Arduino board as an interface. 18 samples were tested, and only 9 samples were calibrated. The experimental results were satisfied and the proposed method achieved the paper objects with acceptable error $\pm 1.4\%$.

Keywords— Turbidity, NTU, laser beam, voltaic solar, Lab VIEW, Arduino, calibration, concentration

I. INTRODUCTION

For thousands of years, aim of getting pure water has been the main big deal for human nation. From this point this research paper is going to continue this aim not only for water, but for many important liquids. The factor that affect the purity of liquid is a turbidity[1,3,4]. Turbidity is an optical property of liquid which is one of the more difficult parameters to measure. It describes how murky or opaque liquid is, which can be defined as:

- The turbidity is the cloudy appearance degree measurement of liquids as shown in Fig.1.
- The turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample.
- In physical terms, turbidity is due to particles of varying sizes dissolved with liquid.
- Is a measure of the degree to which the liquid loses its transparency due to the presence of suspended particles.

Due to sample particles as shown in Fig. 2, Turbidity caused by suspended and colloidal matter such as (clay, slit, fine organic and inorganic mater, plankton and other microscopic organisms).

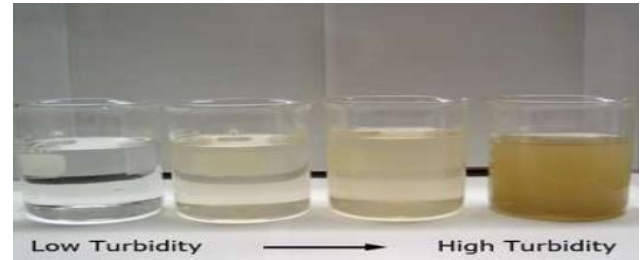


Fig. 1. Turbidity with Appearance Explanation.

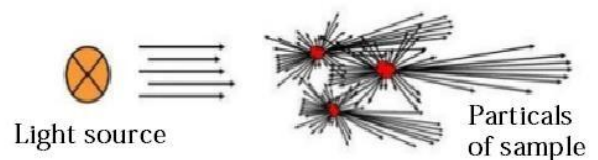


Fig. 2: Effect of Liquid Particles on Light Beam [2].

Turbidity as any quantitative phenomena has a measuring unties which are:

- Jackson Turbidity Unit (JTU)
- Formazin Nephelometric Units (FNU)
- Formazin Attenuation Unit (FAU)
- Nephelometric Turbidity Unit (NTU)

II. SYSTEM STRUCTURE AND COMPONENTS

Fig.3 shows the structure of the proposed system and its operation sequence. The system block diagrams construct of inputs, outputs, and controller.

1. Sample: It is the project input which is measured for turbidity purpose. The sample can be water, water with milk, or water with juice.

2. Laser light: Lasers are devices that produce intense beams of light which are monochromatic, coherent, and highly collimated. The wavelength (color) of laser light is extremely pure when compared to other sources of light, and all of the photons (energy) that make up the laser beam have a fixed phase relationship with respect to one another.

3. Photo voltaic cell: It is the semiconductor responsible for converting laser light to electricity,

Its output is mille volt is sent sending to the Arduino board

4. Hard ware Push button: It is a normally open switch, double pole double terminal (DPDT) push button used to give pulse signal to start testing the sample. There is a resistor and a capacitor connected in parallel with each other and in series with the switch. The use of resistor is to provide load in the line and the capacitor are used to prevent spark and ripples from entering to the Arduino which may have an effect on the sensor reading as shown in Fig.4, [1,2,9,11].

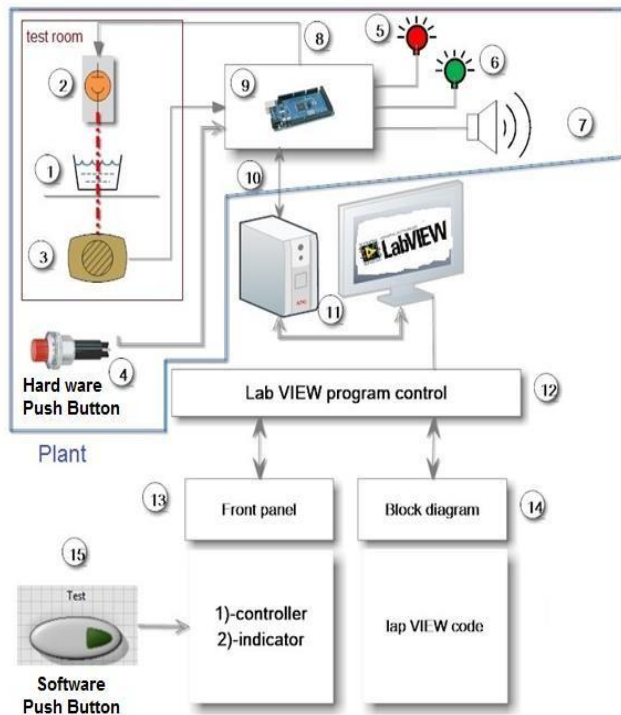


Fig. 3: System Structure of the Project.

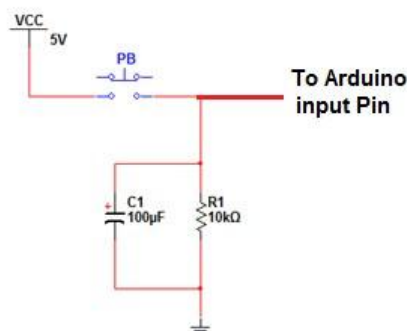


Fig. 4: Loading Circuit.

5. Red LED: LED is a short of Light Emitting Diode which is a semiconductor device that illuminate, when electrons flow through it in forward biased. The function of red LED is to indicate whether the Arduino is connected to the power or not.

6. Green LED: The function of green LED is to indicate if Arduino is connected to lab VIEW program or not.

7. Buzzer (Piezoelectric Buzzer): The function of buzzer is to indicate the operating duration of laser light by producing sound.

9. Arduino Mega 2560: Is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins of which 14 can be used as PWM outputs, 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack and an ICSP header.

The Arduino was used, as interface between real world and lab VIEW software program. It is responsible for converting analogue signals to digital and checking the status of I/O ports and executes lab VIEW codes. It can be said that the Arduino.

12. NI Lab VIEW software program: Lab VIEW is an acronym for Laboratory Virtual Instrumentation Engineering Workbench. Lab VIEW is a graphical programming language that uses icons instead of lines of a text to create applications.

13. Front Panel: The front panel is the user interface of the VI. Front panel builds with controls and indicators, which are the interactive input and output terminals of the VI, respectively. Fig.5 shows the construction of program front panel that is used to control the project and process its data to get reading in turbidity unit.

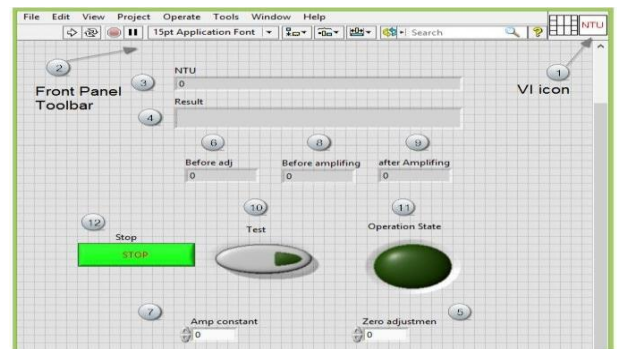


Fig. 5: System Front Panel.

III. SYSTEM CIRCUIT DIAGRAM

Photovoltaic cell is connected to analogue pin number 5 by Read Analogue Pin VI.

- Green LED is connected to digital pin number 6 by Write Digital Pin VI and conFig.d by set digital Pin Mode VI.

- The push button is connected to digital pin number 22 by Read Digital Pin VI. This pin is used to receive a digital signal from push button to operate the code and test starting.

- Buzzer is connected to digital pin number 40 by Write Digital Pin VI to produce sound at testing period.

- Laser light source is connected to digital pin number 44 by Write Digital Pin VI to produce the needed light for testing.

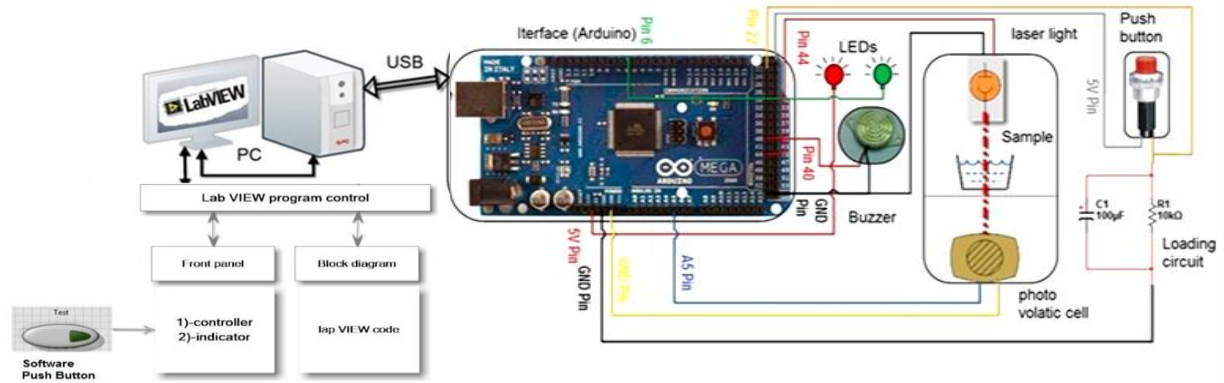


Fig. 6: Circuit Diagram of the Proposed System.

- Arduino board is connected to a PC via USB cable and the actions of Arduino by Lab VIEW commands (code).

- There are three electronic components of project hardware parts that can be assumed as outputs (laser light source, red LED Green LED), and other two as inputs (Push button, photo voltaic cell).

Fig. 6 shows the circuit diagram of the proposed method and how the project components are connected to the Arduino.

IV. METHODOLOGY

A. Calibration Procedure

Before using the device to measure the turbidity, we must follow some procedures to calibrate the device and estimate a formula. Hence, the system was calibrated with a group of different standard NTU kit as shown in Fig.7. This procedure was done to match the reading of device (Voltage) with standard NTU. Each sample of this kit has a value written on its bottle in NTU units. By using nine samples with volume of 40 ml for each sample, we get the readings shown in the table 1[6, 7, 8, 10].



Fig. 7: System Front Panel.

Table 1. System Reading's Calibration

Sample	Sys. Readings(v)	Sample	Sys. Readings(v)
10 NTU	2.5333	500 NTU	2.0629
20 NTU	2.5970	1000 NTU	1.3818
50 NTU	2.6019	2000 NTU	0.9751
100 NTU	2.5725	3000 NTU	0.1078
200 NTU	2.4451	-----	-----

From table 1, we can notice that the relationship between input samples (NTU) and output voltages are not linear. So that, the table above must be evaluated and represented by certain formula.

B. Interpolation of Table Calibration

By set turbidity input value step to 100NTU for each one, we can calculate other turbidity values and their voltages corresponding with using Equ. 1.

$$V = V_{min} + \left(\frac{T - T_{min}}{T_{max} - T_{min}} \right) \times (V_{max} - V_{min}) \quad (1)$$

Where:

V: Voltage output value T : Turbidity input value

V_{min} : Minimum Voltage coordinates value

T_{min} : Min Turbidity coordinates value

V_{max} : Maximum Voltage coordinates value

T_{max} : Max Turbidity coordinates value

After applying the Equ.2, the new results are shown in Table 2.

Table 2. System Reading's Calibration

Sample	Sys. Readings(v)	Sample	Sys. Readings(v)
10 NTU	2.5333	1500 NTU	1.17845
20 NTU	2.5970	1600 NTU	1.13778
50 NTU	2.6019	1700 NTU	1.09711
100 NTU	2.5725	1800 NTU	1.05644
200 NTU	2.4451	1900 NTU	1.01577
300 NTU	2.3177	2000 NTU	0.9751
400 NTU	2.1903	2100 NTU	0.8883
500 NTU	2.0629	2200 NTU	0.80164
600 NTU	1.92668	2300 NTU	0.71491
700 NTU	1.79047	2400 NTU	0.62818
800 NTU	1.65425	2500 NTU	0.54145
900 NTU	1.51802	2600 NTU	0.45472
1000 NTU	1.3818	2700 NTU	0.36799
1100 NTU	1.34133	2800 NTU	0.28126
1200 NTU	1.30046	2900 NTU	0.19453
1300 NTU	1.2597	3000 NTU	0.1078
1400 NTU	1.2191		

Fig.8 shows the comparison of interpolation getting from table 2 with table 1. The interpolation becomes more efficient, resolute, and less in error percentage.

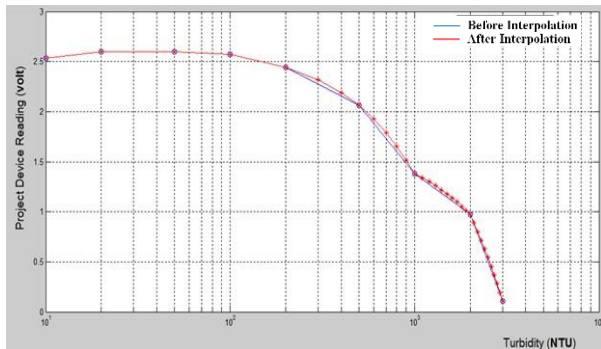


Fig. 8: Comparing between Values in Table 1 and Table 2.

So far, the turbidity has been the input to know how the project device output will be. Also, the interpolation was done to make the graph more resolute and less performing errors.

Now, we have performed an interpolation to estimate the voltage output with 0.1 step considerations by applying Equ.1 to get the new values as shown in Table 3. This has been done to know for every change in voltage how the turbidity would be.

Table 3. System Reading's Calibration

Voltage input	Turbidity Interpolation Output	Voltage input	Turbidity Interpolation Output
0.1	3014 NTU	1.4	987 NTU
0.2	2893 NTU	1.5	919 NTU
0.3	2778 NTU	1.6	869 NTU
0.4	2663 NTU	1.7	766 NTU
0.5	2547 NTU	1.8	693 NTU
0.6	2432 NTU	1.9	619 NTU
0.7	2317 NTU	2	546 NTU
0.8	2202 NTU	2.1	471 NTU
0.9	2081 NTU	2.2	392 NTU
1	1939 NTU	2.3	314 NTU
1.1	1693 NTU	2.4	235 NTU
1.2	1447 NTU	2.5	82 NTU
1.3	1201 NTU	2.6	20 NTU

C. Formula Estimation

To estimate an equation from a graph, Newton's Forward Difference Interpolation Formula is used, which give series formula according to calibration results.

Newton's Forward Difference Interpolation Formula states that for a given table of $N+1$ numerical values $f(x_i)$ at equally spaced points by distance h which equal

$$h = x_{i+1} - x_i$$

Where :

x is input, h is interval

And has general formula which its length specified by number of numerical values in the table or on calibration graph [4]. This formula is:

$$P_N(x) = f(x_0) + u\Delta f_0 + \frac{1}{2!}u(u-1)\Delta^2 f_0 + \frac{1}{3!}u(u-1)(u-2)\Delta^3 f_0 + \dots + \frac{1}{N!}u(u-1)(u-2)\dots(u-N+1)\Delta^N f_0 \quad (2)$$

$$u = \frac{x - x_0}{h} : x \text{ is input, } h \text{ is interval}$$

Buy substitute values of table 3 into Newton's Forward Difference Interpolation Formula (2); there will be 25 Forward Sloping Finite Differences. Also, there will be 26 sections in the estimated formula according to the number of values that have been entered to Newton's Forward Difference method. The estimate equation is.

$$P_{26}(x) = 3014 - 121u + \frac{6}{2!}u(u-1) + \frac{6}{3!}u(u-1)(u-2) + \dots + \frac{263331846}{26!}u(u-1)(u-2)\dots(u-25) \quad (3)$$

$$u = \frac{x-0.1}{0.1}$$

After implementing this formula we have gotten new results as shown in table 4 below.

Table 4. Estimated Equation Results.

Voltage input	Turbidity Interpolation Output	Voltage input	Turbidity Interpolation Output
0.1	3014 NTU	1.4	987 NTU
0.2	2893 NTU	1.5	919 NTU
0.3	2778 NTU	1.6	869 NTU
0.4	2663 NTU	1.7	766 NTU
0.5	2547 NTU	1.8	693 NTU
0.6	2432 NTU	1.9	619 NTU
0.7	2317 NTU	2	546 NTU
0.8	2202 NTU	2.1	471 NTU
0.9	2081 NTU	2.2	392 NTU
1	1939 NTU	2.3	314 NTU
1.1	1693 NTU	2.4	235 NTU
1.2	1447 NTU	2.5	82 NTU
1.3	1201 NTU	2.6	20 NTU

Fig. 9 shows the comparison between estimated equations results and interpolation results in scale graph

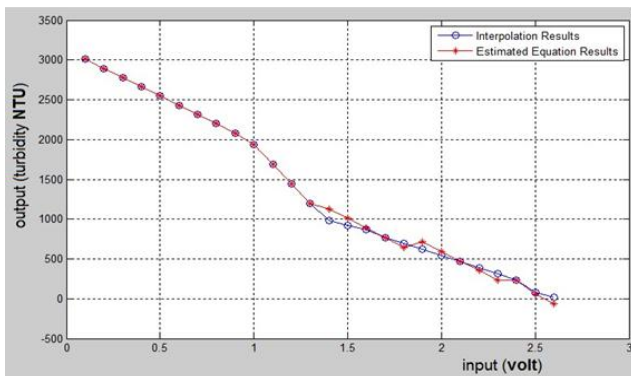


Fig. 9: Comparing between interpolation and estimated equ.

D. Linearity

From estimated equation results of table 4, and **Fig.9** the input values that, can be seen from 0.1 to 1 is linear, after that values fluctuate. So that, to have better values, the data have to be linearizing. There are several ways to determine linearity, leas_ squares linearity is one of them which has calculation formula as:

$$y = mx + b \quad (4)$$

$$m = \frac{n \sum(xy) - \sum x \sum y}{n \sum x^2 - (\sum x)^2} \quad (5)$$

$$b = \frac{\sum(y)}{n} - m \frac{\sum(x)}{n} \quad (6)$$

Where:

x = voltage input, y = turbidity output values, m = slop, b= y intercept of turbidity, n = number of data points .
By applying Equ.4,5,6 on results of table 4, we have gotten new data in table 5.

TABLE 5. ESTIMATED EQUATION RESULTS.

Volt. input	Turbidity Interpolation Output	Voltage input	Turbidity Interpolation Output
0.1	3002.13 NTU	1.4	1322.95 NTU
0.2	2872.96 NTU	1.5	1193.78 NTU
0.3	2743.8 NTU	1.6	1064.62 NTU
0.4	2614.63 NTU	1.7	935.449 NTU
0.5	2485.46 NTU	1.8	806.282 NTU
0.6	2356.29 NTU	1.9	677.114 NTU
0.7	2227.13 NTU	2	547.946 NTU
0.8	2097.96 NTU	2.1	418.778 NTU
0.9	1968.79 NTU	2.2	289.611 NTU
1	1839.62 NTU	2.3	160.443 NTU
1.1	1710.46 NTU	2.4	31.2754 NTU
1.2	1581.29 NTU	2.5	-97.892 NTU
1.3	1452.12 NTU		

Fig.10 shows the comparison between estimated equations results, interpolation results and linearity results in scale graph

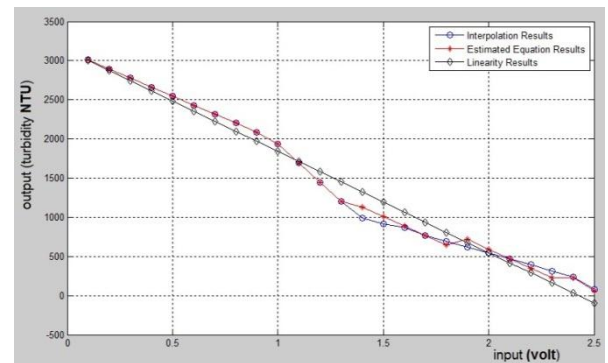


Fig. 10: Comparison between Interpolations, Estimated, Linearity Result.

E. Concentration

To calculate the concentration of a sample, first we should get samples of known concentration, then measuring its turbidity and substitute it in the formula below, the result will be estimation of regression coefficient.

$$a = \frac{TSS^b}{NTU} \quad (7)$$

Where b = 0.96

Getting milk sample which has salts concentration of 1g/L. its turbidity was 3014NTU, by substitute in “8,” the regression coefficient was.

$$a = \frac{0.04^{0.96}}{3014} = 0.0000151 \quad (8)$$

To measure salts concentration of milk we have to apply the results from “8” into “9”

$$TSS = e^{\left(\frac{\log(NTU) - \log(0.0000151)}{0.96}\right)} \quad (9)$$

V. SYSTEM RESULTS AND VALIDATION

Table 6 and table 7 below show water + milk samples and juice samples respectively,

TABLE 6: WATER WITH MILK NTU AND CONCENTRATION.

Water volume	40 mL	60 mL	80 mL
Turbidity(NTU)	1503	2332	2496
Milk Volume 2mL	NTU	NTU	NTU
Turbidity(NTU)	2121	2620	2830
Milk Volume 4mL	NTU	NTU	NTU
Turbidity(NTU)	2389	2779	2943
Milk Volume 6mL	NTU	NTU	NTU
Carbohydrate Concentration 15ml (g/L)	1.825 g/L	1.857 g/L	1.870 g/L

TABLE 7: WATER WITH JUICE NTU.

Water volume	40 mL	60 mL	80 mL
Turbidity(NTU)	26	49	65
Milk Volume 5mL	NTU	NTU	NTU
Turbidity(NTU)	228	287	300
Milk Volume 10mL	NTU	NTU	NTU
Turbidity(NTU)	460	501	590
Milk Volume 15mL	NTU	NTU	NTU

VI. CONCLUSION

This paper has presented the fabrication, implementation and programming of measuring turbidity by using laser beam and solar cell. The proposed method was tested and controlled with monitoring by using lab VIEW software and an Arduino Mega 2560

The Arduino used was ,as an interface between input (solar cell output) and software program input (digital signal). The measuring of water's turbidity with using laser light and photo voltaic cell is possible with an error approach of $\pm 1.4\%$. This theory, also, can be used to measure a specific type of concentration according to the turbidity and type of liquid. Lab VIEW was flexible software program which gives the ability to make data base for tested samples and implementation of any estimated formula of calibration results. The proposed method has been successfully reached the paper objectives.

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