RESEARCH ARTICLE OPEN ACCESS

Enhanced turbidity measurement by modified sensor

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Abstract:

Water turbidity is a measure of relative clarity of water and is the cloudiness of water due to large number of visible or invisible suspended particles present in water. For turbidity measurement in household appliances like dish washer and washing machine the turbidity sensor is installed that checks the light received by the phototransistor that is emitted by light emitting diode. The light gets scattered to all directions due to suspended particles' obstruction. The turbidity sensors in these appliances use only the single phototransistor receiver to pick-up the un-scattered light coming straight from LED. To measure the scattered light by additional phototransistor inside the modified turbidity sensor we get the enhanced realistic turbidity measurement of water. The paper proposes the simple, cost-effective modification in the existing available standard turbidity sensor to collect the scattered light due to the particles present in water with the help of additional phototransistor as a receiver. This has proven to give the enhanced turbidity measurement in NTU (Nephelometric turbidity unit). This modified turbidity sensor takes into account the light scattered by the suspended particles in turbid water. The NTU turbidity sensors available commercially take into account this scattered light but are costly. This paper gives the cost-effective solution for the measurement of realistic turbidity of water in the form of simple modified turbidity sensor that maybe used in household appliances like dishwasher and washing machine to achieve cleaner utensils or clothes.

Keywords — **Water Turbidity in NTU, cleaner clothes and dishes, cost effective NTU turbidity measurement, modified turbidity sensor.**

I. INTRODUCTION

This Turbidity, a measure of clarity of water tells the amount of total suspended solids (TSS) and total dissolved solids (TDS) in water. In short turbidity describes the degree of cloudiness of water. The unit of measurement is nephelometric turbidity units (NTU). Turbidity sensors used in lakes, rivers, ponds, water treatment plants and laboratories for checking water turbidity in NTU take into account the scattered light due to the suspended solids in water at different angles as well. The light beam passing through the clear water without any scattering in a straight line is received by phototransistor or photodiode installed at an angle of 180^0 in a straight line in front of the light emitting diode (LED). Additionally as per the accuracy required, more phototransistors or photodiodes are also installed at an angle of 90^0, 45^0 or at an additional different angular directions. This method is usually termed as nephelometry. The light that scatters in all possible directions due to the particles suspended in water is collected by such various photodiodes or phototransistors installed at different angles inside the sensor assembly other than the one in a straight line at 180^0. This gives the complete turbidity measurement in NTU of the water sample in which the sensor is installed or inserted.

On the other hand, the household appliances like dishwasher and washing machine use simple, low-cost electronic turbidity sensor that has the receiver to collect the light in a straight line only. Such simple cost-effective turbidity sensor available in the market is having a single LED and a single phototransistor or a photodiode as a light transmitter and a photodiode or phototransistor as a receiver respectively. Hence the size of the sensor is compact and hence has the limited use mostly in

home appliances like dishwasher, washing machine and in laboratory testing facilities of water. The water clarity in terms of turbidity is measured in such appliances by this simple straight-line light detecting turbidity sensors and in turn they decide whether further washing is required or not. If the water is still turbid, the next fresh and clear water is pumped in after draining the earlier turbid water out of the washing chamber. There is no provision inside the sensor assembly to collect and measure the scattered light at different angles. The un-scattered light received in a straight line by a single phototransistor or a photodiode installed exactly in front of the LED at an angle of 180^0 is only detected and measured to decide the next washing cycle of the appliance. This sensor is simple and also cost effective as compared to the high-cost commercial sensors used in nephelometry.

To have the low-cost nephelometric turbidity sensor giving reasonable accountability of the scattered light as well we can install at least one phototransistor at an angle of 90^0 inside the existing contemporary simple electronic turbidity sensor. Such a modified sensor when used in home appliances like washing machine or dishwasher detects the turbidity in water more effectively. The water that is detected clear or non-turbid by using simple contemporary electronic turbidity sensor in its last cycle of washing now may appear cloudy or turbid due to the sediments or particles which might be still present in water. The next wash cycle is now made on to wash or rinse so that the remaining mud or dirt particles are removed. This gives the better cleaning of the clothes or utensils in the said washing machine or dishwasher units when such a modified turbidity sensor is used in lieu of contemporary, simple, straight-line light detecting electronic turbidity sensor.

II. BACKGROUND

Water is life. For every living organism water is required for the survival. Human beings need water for many more other purposes than just for drinking, cooking or washing and bathing. Due to industrialization and agriculture, we need water for numerous other purposes too. Each application and usage of water though different requires some or the other quality-check of the water parameter. Starting from potable water used for drinking and cooking, washing clothes and utensils also are the basic necessities of every house. For the appropriate usage of water, one should know the basic water quality parameters like turbidity, pH, salinity, TDS, hardness, conductivity, dissolved oxygen, bacteria and many more.

As far as turbidity is concerned there are many applications where turbidity is of utmost importance. There are old methods of measuring turbidity in laboratory followed these days by the new electronic sensors to measure turbidity in real time, remotely. There are many electronic sensors available these days for commercial and laboratory measurements of turbidity. Researchers have explored to have the low cost NTU turbidity sensor by using different methods. In this method the light from light emitting diode is obstructed by the sediments in water before it reaches the photodiode installed in the standard turbidity sensor. The water passes through the small gap between the light emitting diode and phototransistor. When the particles in water obstruct the light which otherwise would have gone straight towards 180^0 towards phototransistor, now gets scattered in many directions along with the 90^0 angles of scattering. There are forward and back scattered light angles too and all these angles of light scatter should be taken into consideration by installing the phototransistors at the different angles.

Out of these various light receiving points, angle of 90^0 is considered to be the most advisable point of scattered light detection with turbidity measurement limit of 0 to 40 NTU. Back and forward scattered light is said to be the measure of high turbidity value >1000NTU hence cannot be measured using only the straight line detection. [21].

The standard parameters of water quality may be referred for the appropriate usage of the water for various applications and uses. For potable water the water turbidity under consideration must be below 5 NTU. For washing of clothes and utensils the

cleanliness is measured in terms of turbidity of drained out water after each washing cycle. Usually, the turbidity levels are very high before the first washing cycle due to soiled clothes, detergents and mud particles. This value may be as high as 200 NTU. After the consequent washing cycles the turbidity of the discharged water goes on reducing and finally reduces to 10 NTU or even below that.

Real time turbidity measurements use simple turbidity sensor with analog to digital converter and a suitable microcontroller. This method is widely used by many researchers for water quality measurement including turbidity. They have used wireless sensor network (WSN) using simple microcontroller like Arduino or Raspberry Pie with the allied hardware and software. The output is either seen on a display and is recorded with the help of suitable wireless interface on mobile phones or even saved on desktops or laptops using data acquisition hardware as per the requirement. [10]. All of these experiments have used a simple, available, low cost turbidity sensor for the turbidity measurement. This has given the turbidity readings up to maximum 5 NTU. For drinking water, the acceptable limit for NTU is 1 and in worst conditions in the absence of alternate water resource it is maximum 5 NTU. [3].

Standardization on water quality indices or parameters by various government organizations and agencies is also available as the reference for the water quality measurement. [2], [3].

The comparison of NTU measured by any electronic sensor is usually done with the laboratory measurements of the same sample. This confirms the readings or suggests the modifications in the sensing methods and techniques.

III. ARCHITECTURE OF ELECTRONIC TURBIDITY SENSOR USED IN APPLIANCES

The standard, simple, low-cost electronic turbidity sensor is available in the local market at a few hundreds of Indian Rupees. This is a contemporary turbidity sensor used inside the household appliances like washing machine and dishwasher to detect the turbidity of water after each washing cycle is completed. It uses light transmitter in the form of a LED and a light receiver in the form of a phototransistor (see Fig. 1). This turbidity sensor measures the cloudiness of the discharged water in NTU after each washing cycle to check the clarity of water. It usually checks this whether it is below 20 or not. If it is not then the next wash cycle is made on by pumping in fresh and clear water and the process is repeated.

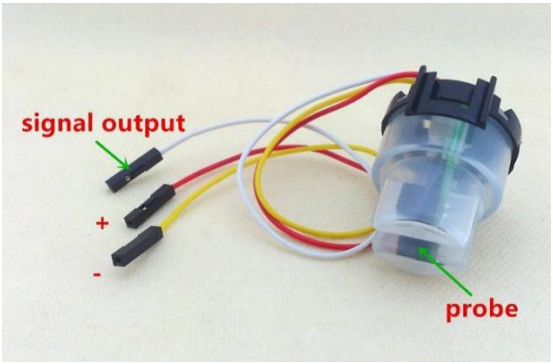

Fig.1. Standard Turbidity Sensor

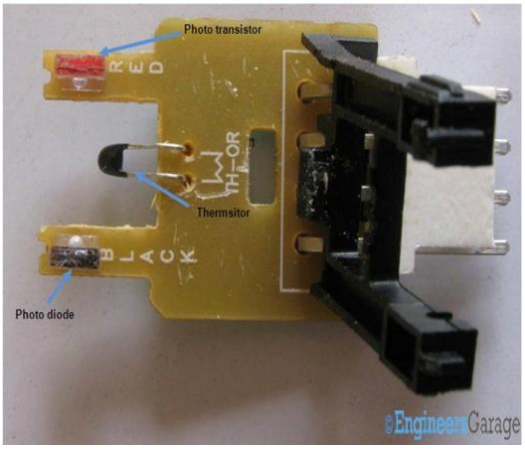

Fig.2. Standard Turbidity Sensor inside

IV. ARCHITECTURE OF MODIFIED TURBIDITY SENSOR WITH ADDITIONAL PHOTOTRANSISTOR INSTALLED INSIDE

As clearly seen below, the contemporarily available simple electronic turbidity sensor used in home appliances is now modified by installing one phototransistor at an angle of 90^0 with respect to the existing original photodiode and phototransistor inside the sensor assembly (see Fig. 3, Fig. 4). We have modified this simple electronic turbidity

sensor used in washing machines or dishwashers and developed a cost-effective modified turbidity sensor by installing a phototransistor inside the existing assembly of the available sensor.

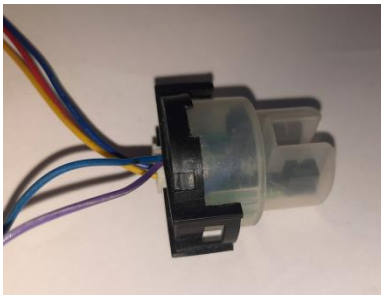

Fig.3. Modified Turbidity Sensor with additional phototransistor

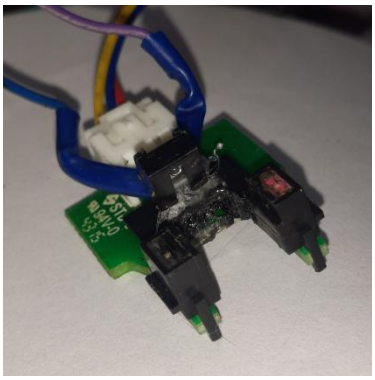

Fig.4. Modified Turbidity Sensor with phototransistor seen inside

The modified turbidity sensor also keeps checking the clarity of water at the end of each washing cycle for the clarity of water. Once the water turns clearer without any sediments or cloudiness due to the mud particles more light is received by the original phototransistor in a straight line at 180^0 which is in a straight line from LED as well inside the sensor. After the consecutive washing cycles of the washing machine the water should become clearer indicating that the mud particles are removed thoroughly. When negligible or no light is detected by the phototransistor installed at an angle of 90^0 inside the sensor assembly and maximum light is detected by the phototransistor installed at an angle of 180^0 the washing is said to be complete. This time the water is clearer and without any mud particles, sediments or cloudiness in it which otherwise is not seen when the simple un-modified sensor is used.

V. EXPERIMENTATION

The readings and the graph below indicates the betterment in the measurement of turbidity in NTU by using additional pick-up of the scattered light inside the existing simple and standard turbidity sensor.

TABLE 1.TURBIDITY READINGS IN NTU, AT 280 C TEMPERATURE

Sample No.	Un-modified turbidity sensor readings (NTU without scattered light pickup)	Perception of turbidity with no modification in sensor Turbidity Level	Modified turbidity sensor readings (NTU with scattered light pickup)	Perception of turbidity with modified sensor Turbidity Level
1	3.0	Low	5.0	High
2	2.0	Low	5.0	High
3	3.2	Low	5.0	High
4	0.0	Zero	2.0	Low
5	3.6	Low	5.0	High
6	3.4	Low	5.0	High
7	3.6	Low	4.8	High
8	3.4	Low	5.0	High
9	3.4	Low	5.0	High
10	3.4	Low	5.0	High
11	3.4	Low	5.0	High
12	3.4	Low	5.0	High
13	3.2	Low	4.8	High
14	3.0	Low	4.6	High
15	3.0	Low	4.8	High
16	3.0	Low	4.8	High
17	2.8	Very Low	4.0	High
18	2.6	Very Low	4.0	High
19	2.6	Very Low	4.0	High
20	1.0	Negligible	3.4	High
21	0.0	Zero	2.0	Low
22	0.0	Zero	1.0	Negligible
23	0.6	Negligible	2.0	Low
24	0.0	Zero	2.0	Low
25	1.0	Negligible	3.0	High
26	2.0	Low	4.0	High
27	2.5	Low	4.8	High
28	1.5	Low	4.0	High
29	1.8	Low	3.1	High
30	2.2	Low	4.2	High

Turbidity measured by the modified turbidity sensor with additional light pick-up at 90^0 gives enhanced and closer reading of turbidity than the simple un-modified turbidity sensor with only 180^0 light pick-up.

With the modified turbidity sensor as discussed above, the various water sample readings are taken in the laboratory with a variety of turbidity and cloudiness of water. The experimentation is done by using simple contemporary un-modified standard electronic turbidity sensor available easily in the market at a very low price. Thirty different samples of water are taken with different amounts of turbidity for each sample. These water samples are collected from various locations in bottles for the ease of carrying them. After collection, these samples are poured turn by turn in the glass. Each sample so taken in the glass is checked for the temperature and it is found to be of 28^0 C, for each sample. Then the two sensors, modified and un-modified, are taken at a time and inserted in the glass of sample water. The readings are simultaneously taken for each water sample to check the turbidity with the modified turbidity sensor with additional 90^0 scattered light reading and the standard sensor reading without scattering as well. The readings are taken simultaneously by inserting the two turbidity sensors, modified and un-modified, at a time, in the same container having the sample of turbid water. These readings are taken for each sample of turbid and cloudy water. The readings are then compared and the graph is plotted for the comparison purpose. These readings are taken with the help of Arduino Uno microcontroller connected to the desktop in the laboratory.

The outputs of the standard turbidity sensors, both modified and un-modified sensor, is connected to the separate microcontroller through separate analog to digital converter (ADC) circuit. The real time readings are taken using Arduino interface on the desktop. These readings are then converted to the plot of samples versus NTU. The modified turbidity sensor readings and un-modified turbidity readings are taken under the same temperature and physical conditions for each turbid sample of water.

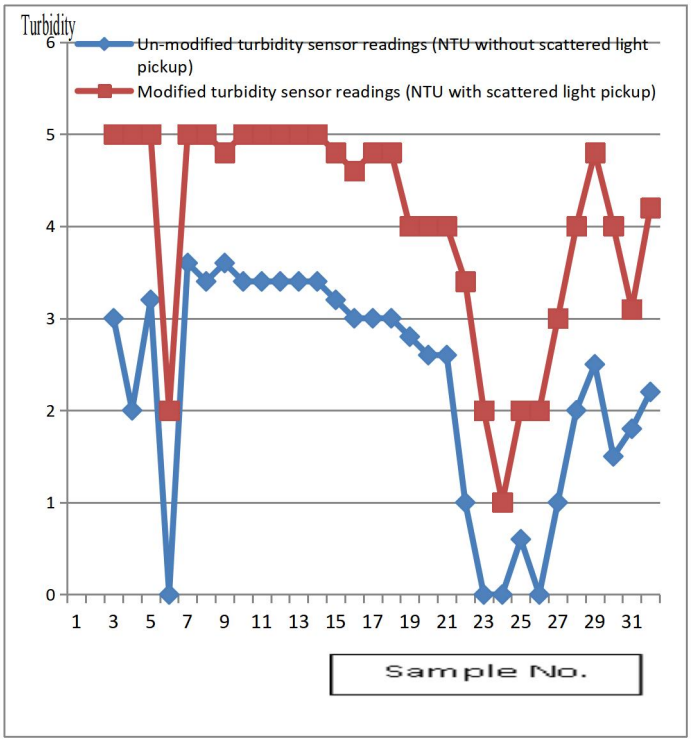

Fig.5.Graph of modified and un-modified turbidity reading for each sample as in Table 1.

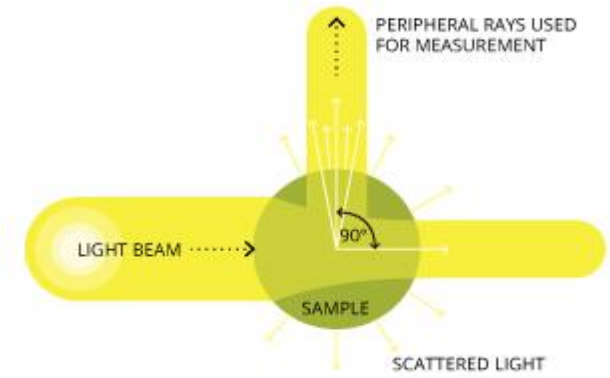

Fig.6. Scattered light due to particles in water explained

VI. CONCLUSION

It is observed that the un-modified simple turbidity sensor which is contemporarily used in household appliances like dishwasher or washing machines gives the turbidity measurement with its

own limitations. This is due to un-accountability of the scattered light inside the simple turbidity sensor.

The modified turbidity sensor in turn gives the enhanced measurement of turbidity by collecting the scattered light at 90^0 inside the turbidity sensor along with the light collected in a straight-line at 180^0 angle as well.

The difference in the two readings for each sample under consideration shows the difference of at least 1 NTU up to 3 NTU, that is negligible turbidity to high turbidity. As far as application in the washing appliance is concerned this shall result in better cleaning of the clothes or utensils by giving out clearer and non-cloudy water through the appliance.

VII. LIMITATIONS

Such a modified sensor cannot measure the turbidity beyond 10 NTU. Hence for the applications of such a modified sensor other than that in the home appliances like dishwasher and washing machine, we should use the commercial turbidity sensors. The turbidity measurement of highly turbid water sample turbidity measurement in the laboratory we need to have standard commercial sensors with measurement capacity above 10 NTU.

VIII. FURTHER SCOPE

Such a sensor modified using simple available phototransistor shall be used to mass produce the sensor by redesigning the inner components. Three D printer can be used to design and develop the casing of the modified sensor to accommodate the additional phototransistor for the additional angle light pick-up. The components and casing can also be developed further to achieve the measurement of NTU beyond 10 up to 100 or even more for the commercial usage of the sensor in industry.

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