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CMOS COLOUR SENSOR BASED pH MEASUREMENT FOR WATER QUALITY ANALYSIS

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ABSTRACT
A Real-Time pH measurement system using a novel design Programmable CMOS optical Colour light to frequency converter TCS230 is presented. The system uses Bogen's universal indicator solution combined with a white light source and the Programmable CMOS colour sensor TCS230 to measure pH as a function of colour change in a sample. Bogen's universal indicator solution causes a colour change in a sample according to the pH of the sample. The output frequency from the colour-sensitive CMOS RGB photodetector chip is proportional to the pH of the sample. Experimental results show that this Programmable CMOS Colour sensor system can determine the pH of a sample from pH 1 to 10 in real-time.

***Keywords**: Programmable CMOS optical Colour sensor TCS230, PIC Microcontroller 16F877A, pH measurement, RGB colour sensor, CIE colour space, Spectrometer .*

I. INTRODUCTION
The CMOS colour and intensity sensitive chip is used to measurement of the pH of water in rivers or lakes in realtime. The pH of a body of water is an excellent indicator of the relative level of pollution; typical water pH values are between 6.5 and 8.4. A slight change of pH can kill organisms normally found in water. pH plays an important role in indicating the quality of drinking water. This paper proposed to modernize the pH measurement by using RGB Color sensor that is interfaced to the Digital Computer. Estimation of the analyte concentration is to be done as that of
using RGB data received from the color sensor instead of Aborbance. The RGB data is to be converted to its equivalent hue and saturation as per the Chromaticity Diagram. The pH value can be estimated from the saturation of the Color.
Optical pH sensors are generally not as bulky or fragile as standard methods for measuring pH, such as glass pH electrodes and pH meters nor do they require expensive electrodes, nor frequent recalibration [1]. Also, optical pH sensors are more easily fabricated using commercial CMOS standard processes without post-processing deposition [2-3].
The heart of the sensor system is a novel designed neuromorphic optical sensor. The sensor is termed 'neuromorphic' because its functionality and processing structure are derived from biological structures. Types of analogue very large-scale integration (AVLSI) systems have shown that it is possible to develop compact, low-power, and real-time smart sensor microsystems on a single chip for various applications [4–5]. The proposed method is superior in two aspects. One is the non-requirement of monochromatic source in the Colorimeter and the second one is the automation of chemical Laboratory. The remainder of the paper is organized as follows. In section II, the proposed system descriptions are explained the colour measurement techniques for pH value measurement. The experiment result is presented in section III. Finally, we conclude the experimental result in section IV.

II. SYSTEM ARCHITECTURE
In this section we describe the architecture of the CMOS Colour Sensor based pH measurement system design for water quality analysis, which includes the TCS230 optical Colour sensor to sense the light intensity in the form of frequency for RGB detection and PIC microcontroller 16F877A, LCD unit for display pH value.

A) RGB CMOS Sensor Assembly

The RGB CMOS Sensor Assembly designed to measure the colour of water to process of pH measurement. Light from the source passes through the liquidsample in the cuvette, and is then detected by the sensor chip, which has an integrated CMOS photodetector and processing circuitry.

Bogen's universal indicator is added to the liquid sample, which causes a colour change in the sample according to the sample's pH. The output of the sensor chip is a frequency that is proportional to the relative colour components in the detected light. The chip has a photodetector for irradiance detection, a different photodetector for different wavelength detection. In this system, only the wavelength detection channel is used as the optical receiver [6-7].

The Color sensor illuminates a sample using in-built red, green and blue LED light sources (one colour at a time) and records the quantity of light reflected back from the object. TCS230 colour sensor operates by illuminating the object with two white LEDs, while an array of photo detectors (each with a red, green, blue and clear filter) interpret the colour being reflected by means of a square wave output whose frequency is proportional to the light reflected. The TCS230 Colour sensor has a 5.6-mm lens, which is positioned to allow an area of 3.5 mm2 to be viewed. A USB4000 spectrometer (Ocean Optics Inc., FL, USA) was used to find the height at which the greatest intensity of light occurred when the RGB sensor was placed above a sample. The two white LEDs are directed down at an angle, there is a point where the light intensity is the greatest. This position was 20 mm above the surface of the sample, as shown in Figure 1.

Since the TCS230 is mounted 20 mm above the sample, and therefore not in direct contact with the sample, it was more suited for sensing RGB value than the full contact required by the Color sensor [7].

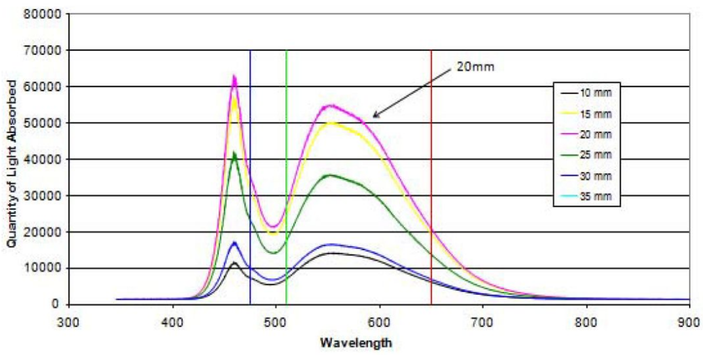

Fig.1. Light absorbed from TCS230 across the white LED light spectrum when the sensor is positioned at 6 different heights

B. Experimental Setup

In proposed work used various solutions as samples in our experimental observation. Programmable RGB color sensor TCS230 and White LEDs are mounted on a specially designed PCB, below the TCS230 sensor and White LED a sample whose color is to be measure is placed. When the sample is illuminated with white LED notes the reflectance (O/P of TCS230 in the form of frequency). The reflectance for various solutions with white LEDs is recorded. These reflectance values inputs to a microcontroller based controlling unit for calculate the tristimulus values equation (1). Once we calculate tristimulus values we can calculate chromaticity coordinates of all samples using equation (2). The results of solutions measurement are compared with the analysis performed with the help of Ocean Optics HR-4000 high resolution spectrophotometer.

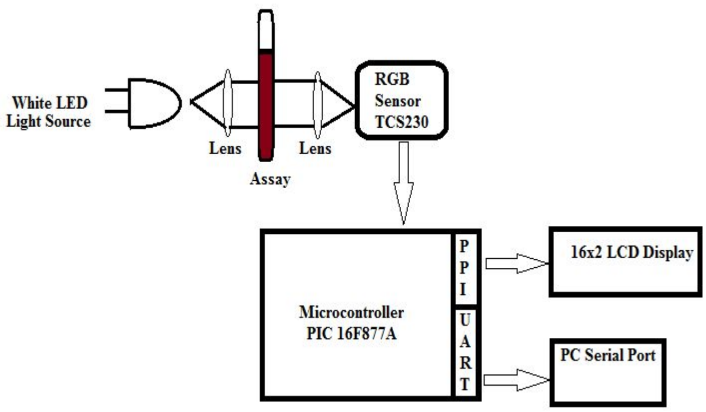

Fig.2. Block Diagram of CMOS RGB Colour Sensor TCS230 Based pH measurement system using PIC µcontroller 16F877A.

C. Color Measurement Technique

From the three variable RGB data, Color's hue and saturation can be obtained using Chromaticity diagram. Since Color of the assay is constant irrespective of the value of pH.

1) CIE 1931 Chromaticity Diagram

A diagram which is convenient for Color measurement is the Horse Shoe shaped Chromaticity diagram. The positions of the various Colors, from Blue (400nm) at one end to Red (700nm) at the other end, are indicated on the curve. Any point not actually on the solid line curve, but within the area enclosed by the curve, represents not a pure spectrum of Color, but a mixture of spectrum Colors. As White is such a mixture, it too lies within this area, specifically at point C shown in Figure 3. The most intense Colors i.e., Red, Green and Blue, in their deepest shades, are obtained at the outer edge of the diagram. The more familiar Color shades such as Pink, light green, pale blue appear when moved towards the centre. Finally at the centre comes the White point C.

The term hue is associated with the dominant wavelength. Thus, hue represents the basic Color as it appears to us while saturation tells how deep the Color is. It is possible to specify the saturation of a Color on basis of its distance from Illumination point C. Chromaticity values depend on only dominant wavelength and saturation, and are independent of the amount of luminous energy. For example, a brown color is not on the diagram; however, a brown is just a low-luminance orange-red. A standard white light source (formally called illuminant C) is located near (but not at) x = y = z = 1/3. If two colors are represented by points C1 and C2, the additive mixture is a point C3, lying somewhere on the line C1C2. Complementary colors are those that can be mixed to produce white light. If a line is drawn from the white point through a point representing a specific color, the intersection of this line with the spectral locus defines the dominant wavelength.

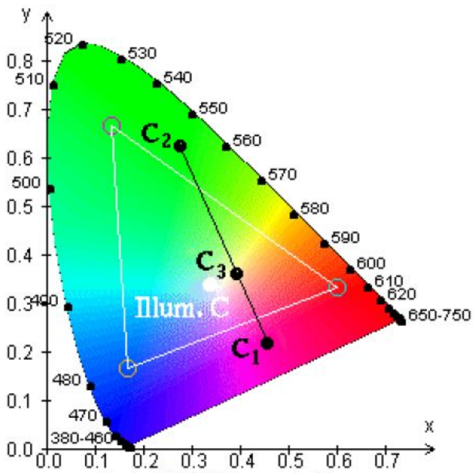

Fig. 3. CIE Chromaticity Diagram

If the line crosses the purple boundary, the dominant wavelength cannot be defined, and such color is called non-spectral. Indeed, there is no magenta in the rainbow.

2) Conversion of RGB Data to Hue and Saturation

Conversion of RGB to XYZ takes the form of simple matrix transformation. Chromaticity coordinates x, y and z are obtained from the Tristimulus values X, Y and Z.

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$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 3.240790 & -1.537150 & -0.498535 \\ -0.969256 & 1.875992 & 0.041556 \\ 0.055648 & -0.204043 & 1.057311 \end{pmatrix} X \begin{pmatrix} R \\ G \\ B \end{pmatrix} \qquad (1)$$

$$x = \frac{X}{X+Y+Z}; \quad y = \frac{Y}{X+Y+Z}; \quad z = \frac{Z}{X+Y+Z} \qquad (2)$$

Table 1: CIE 1931 Chromaticity Coordinates

Wave length [nm]	Chromaticity coordinates			Slope of the Color
	x	Y	z	
400	0.173337	0.004797	0.821866	2.05340
420	0.171407	0.005211	0.823583	2.02704
440	0.164412	0.010858	0.824730	1.90902
460	0.143960	0.029703	0.826337	1.60334
480	0.091294	0.132702	0.776004	0.82892
500	0.008168	0.538423	0.453409	-0.63072
520	0.074302	0.833804	0.091894	-1.93209
540	0.229620	0.754329	0.016051	-4.05922
560	0.373102	0.624450	0.002448	7.32033
580	0.512486	0.486591	0.000923	0.85546
600	0.627037	0.372491	0.000472	0.13332
620	0.691504	0.308342	0.000154	-0.06977
640	0.719033	0.280935	0.000032	-0.13585
660	0.729969	0.270031	0.000000	-0.15898
680	0.733417	0.266583	0.000000	-0.16684
700	0.734690	0.265310	0.000000	-0.16948

Hence, conversion of RGB data to its equivalent Chromaticity coordinates can be done using the above two equations. The Chromaticity coordinates that were adopted by the International Commission on Illumination for the various spectrum Colors are given in Table 1. Slope of the line gives the value of Hue and this Slope of the Colors with respect to the luminance point C in CIE 1931 Color space is calculated using equation (3) if the Chromaticity coordinates x, y and z are known.

$$Slope = \frac{(y_{white} - y)}{(x_{white} - x)} \qquad (3)$$

Where $x_{white} = y_{white} = 1/3$. Hence, hue can be measured. It is possible to specify the saturation of a Color on the basis of its distance from point C.

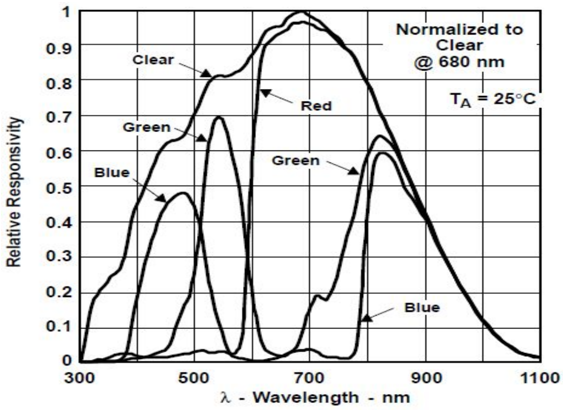

Fig.5. Photodiode Spectral Responsivity of TCS230 Sensor

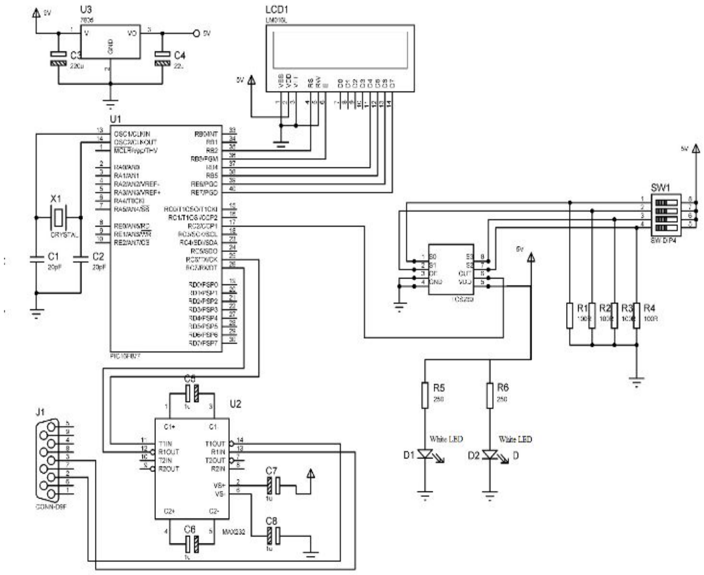

Fig.3. Schematics of Programmable CMOS RGB Colour Sensor TCS230 Based pH measurement system using PIC µcontroller 16F877A.

III. RESULT

In proposed work measured the light for different pH values these results are shown in Figure 4a and 4b. These data show that the light impinging on the Programmable RGB colour sensor TCS230 input to the wavelength detection channel is not monochromatic, but rather composed of a broad range of colours.The peaks of the more acidic colours show a clear shift to shorter wavelengths as the sample becomes more neutral. The spectra of the higher pH solutions show a continued peak shift to shorter wavelengths, but there is also evidence of the non-ideal white light source affecting the shift. The light source has a much smaller spectral component above 450 nm, which limits the 'peak' for the green to blue coloured samples.

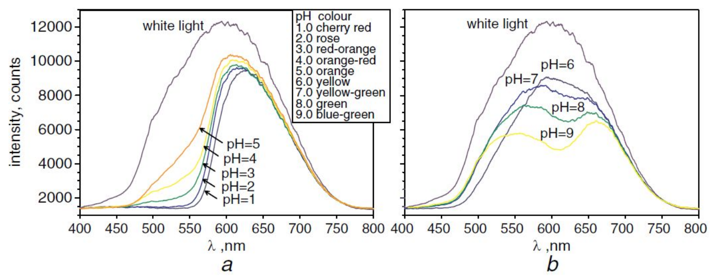

Fig.6. Output response of liquid sample for different pH values.

Figure 6 shows the output response of the system to liquid samples having different pH values. In each experiment, 2 ml of the sample is injected into the cuvette and mixed with 10 ml indicator solution. The final colour of the mixed solution indicates the pH of the sample, and the output from the wavelength detection channel on the chip represents the colour of light. From Figure 6, we can show that the RGB colour sensor TCS230 output decreases monotonically for an increasing pH of the sample. The error bars indicate one standard deviation of the measured output for repeated experiments. For an inexpensive generic white light source, the response is very good. Having a broader and flatter white light source would improve the resolution at higher pH values. Referring to Figure 6, we can see that the intensity of the light source at 600 nm is almost seven times that at 475 nm (blue). Because of this, as the sample colour shifts to shorter wavelengths, the peak of the response shrinks, which causes the higher intensity peak at 650 to 700 nm to become more prominent. In proposed system's output response shown in Table 2. The only result of the dual-peaks is that the response is limited to a pH range of between 1 and 8–9 (pH values beyond 9 are not uniquely resolvable).

Table 2: pH value and Chromaticity Coordinates

pH	Chromaticity Coordinates			
	Measured data		Using Ocean Optic data	
	x_0	y_0	x	y
1.0	0.28	0.21	0.28	0.21
3.0	0.26	0.26	0.27	0.27
4.0	0.24	0.14	0.23	0.13
5.0	0.26	0.32	0.27	0.32
5.5	0.26	0.34	0.26	0.34
6.0	0.29	0.34	0.29	0.34
6.5	0.30	0.37	0.30	0.37
7.0	0.27	0.34	0.26	0.34
7.5	0.41	0.51	0.40	0.50
8.0	0.28	0.37	0.28	0.37
8.5	0.37	0.39	0.37	0.39
9.0	0.38	0.40	0.38	0.40
9.5	0.38	0.35	0.37	0.35
10.0	0.37	0.39	0.37	0.39

IV. CONCLUSION

We present a real-time Programmable CMOS colour sensor TCS230 based pH measurement system. We have demonstrated that the system can successfully determine the pH value of a liquid sample over a broad pH range. Experimental results show that the Programable RGB colour sensor TCS3200 is a useful low cost colour sensor, which following calibration can provide accurate RGB readings. It is therefore a useful component for integrating into an automated monitoring and analysis of Water quality system.

Further test results will be presented in an extended version of this paper. It will also include investigations into a CIE Least Squares Regressions approach as an alternative method to calculating the gamma calibration factor.

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