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International

Journal

Of Modern Engineering Research (IJMER)

Portable Water Color Monitoring System Using Microcontroller for Phytoplankton Bloom Measurement in Japanese Lake

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ABSTRACT: *Rapid assessment of algal blooms in lakes has been difficult due to lack of inexpensive and portable measurement systems and lack of spatial resolution from current freely available satellites. Here we demonstrate the capacity of a low-cost, portable water color monitoring system in assessing phytoplanktonbloom (chlorophyll concentrations ranged from 0.4 to 48.9 mg/m3)* intothe*Lake Senba, Ibaraki Prefecture, Japan.We developed two types of instruments, one is using three color LED and the other is using small spectroscopic module. The design of these systems and result of fundamental experiment is reported.*

KEYWORDS*: water color, water environment, phytoplankton bloom, microcontroller, LED, spectroscopic module*

Date of Submission: 20-07-2018 Date of acceptance: 03-08-2018

I. INTRODUCTION

The world faces unprecedented crisis in water environment at present. Sustainable use and management of water bodies cannot be done without understanding the changes of water quality and also the direct and indirect impacts of man for those. Sudden water quality measurements for special issues and continuous water quality monitoring very much important for the maintain water bodies and pollution prevention. For water quality measurement different commercial instruments are available for targeting different parameters (Dahanayaka*et al.*, 2012; 2013, Kishino*et al.*, 2005). Chlorophyll-a and total suspended solids are important factors in water quality monitoring. These two parameters describe water body's tropic states as well as pollution level. The correct values of those, support management and sustainable use of water bodies through proper management and mitigation measures of water quality (Homma*et al.*, 2008). To measure these two parameters there was several methodologies including laboratory analysis of water samples, satellite imagery analysis as well as in-situ measurements using commercial available instruments (Dahanayaka*et al.*, 2012; 2013, Zeng *et al.*, 2017). For instrumental measurements there was different type and different category instruments. Spectrometer is one of most commonly used instrument for measure those parameters. Commercial available spectrometers are relatively very much expensive and difficult to use in developing countries according to high price. And also, these instruments have some advantages as well as disadvantages (Lakesh*et al.*, 2014a; 2014b; Satyanarayana and Mazruddin, 2013; Sahota*et al.*, 2011). Therefore, developing low cost water color monitoring system is necessary for measure water quality in general purposes as well as research works. Therefore, current study target on fulfill those gaps and develop more accurate portable water color monitoring systemwith low cost, small size and low power consumption.

Various sensors and microcontrollers with low price are available in recent years (Anuruddha*et al.*, 2013). We developed two types of instruments using small microcontrollers for water color monitoring. One is composed with three color LED and phototransistor. The other is composed with white LED and small spectroscopic module. Main target of our measurement is phytoplankton blooms in lakesof Japan.The generation of phytoplankton bloom is one of the major water pollutions (Lakesh*et al.*, 2014a, Hiroomi*et al.*, 2013). The generation of phytoplankton blooms in summer season is a social problem in Japan. In this paper, design of these systems and results of fundamental experiment is reported.

II. CONCEPT OF DEVELOPMENT

Water color is measured by dipping a device in the water or using collected water samples. Light transmitted by light source propagates in the water and received by detector. Light is absorbed in the water. Received light signal,P is expressed by Lambert–Beer law as follows,

$P=P0\exp(-\alpha L)$

where, P0 is source light power, α is absorbance and L is the length of optical path. The α is a function of optical wavelength. If we use three color LEDs and photodetector, we can measure absorbance at different colors. The absorbances are averaged values of each LED colour. If we need more detailed information of absorption spectrum, we can use spectrometer. Conventional spectrometers are expensive and not portable, however small spectroscopic module are available owing to the development of Micro-Electro-Mechanical Systems (MEMS) technique. If we use white LED as light source and spectroscopic module, we can measure detailed information of the absorbance of water.

III. DEVELOPMENT OF THREE COLOR LED SYSTEM

Figure 1and 2 show the concept of three color LED system and the photo. The system is put on the water and absorbance of water is measured around the water surface. We used the Arduino (Atmega 328), three color LED (Red, Blue and Green) and, phototransistor. The LED emits Red, Blue and Green light in sequence, and the phototransistor receives the emitted light. Figure 3 shows the circuit of three color LED system. We fixed the LED and phototransistor both sides of plastic tube whose diameter is10cm. The LED and phototransistor exist in parallel 10cm under the water surface. The design of the system was determined through trial and error. For example, an air bubble between the LED and detector should be avoided, because an air bubble affects the propagation of light. When we put the system, an air bubble cannot remain in the plastic tube.
Figure 4 shows the flowchart of measurement. Three color LED illuminates in short time. The phototransistor was installed with a resistor in series. The voltage of resistor corresponds to the intensity of received light. The voltage was measured by 10-bit AD converter of Arduino.

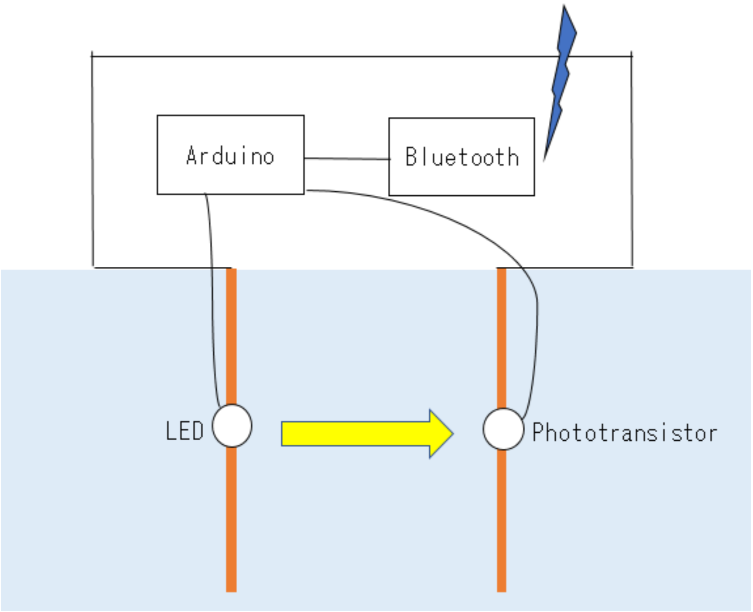

Figure 1: Concept of the three-color LED system

Figure 2: photo of three color LED system

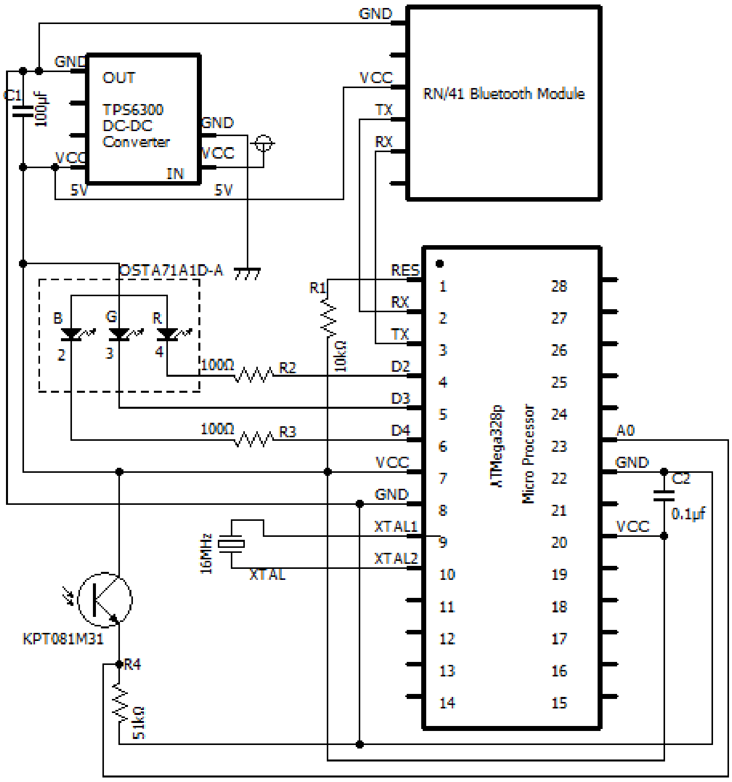

Figure 3: Circuit diagram of the three color LED system

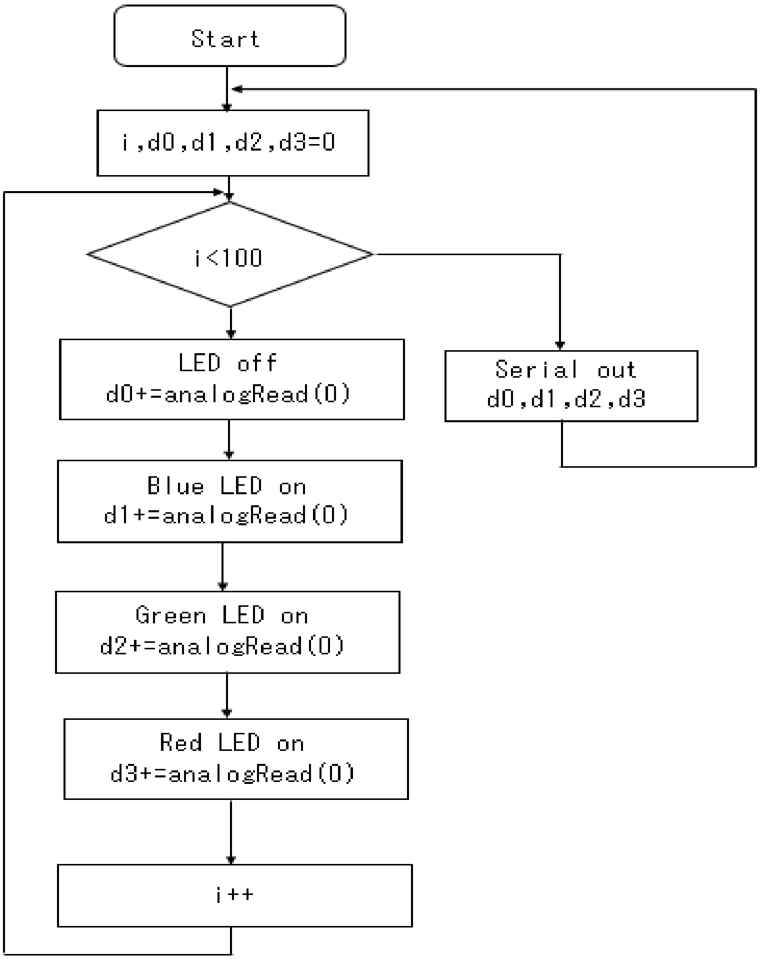

Figure 4: Flow diagram of the measurement system

To measure water color around water surface effectively, we separated measurement system from monitor computer. Tablet computer or note computer were used. Android and Windows were used as Operating System. The Arduino send data to the computer via Bluetooth and the Serial Port Profile (SPP) was used for communication.

The procedure of measurement is as follows. The system measures intensities of received three color lights,Pr0, Pg0 and Pb0 using pure water as calibration.Then the system was put on the water surface of lake or pond. The received intensities of three color lights are Pr, Pg and Pb.

The absorbance at red color is expressed as$\alpha r=\log(Pr/Pr0)/L$

Where L is the distance between the LED and the phototransistor. The absorbance at green and blue are expressed as similar equations.

Fundamental test was carried out using test water in the laboratory. Colored liquids were prepared using food dyes for coloring the water.

The absorbance of these liquids was measured by developed system and a spectrometer (SP-300) as shown in Fig. 5. The central wavelengths of R, G and B lights are 625nm, 525nm and 470nm, respectively. They are relatively coincident each other.

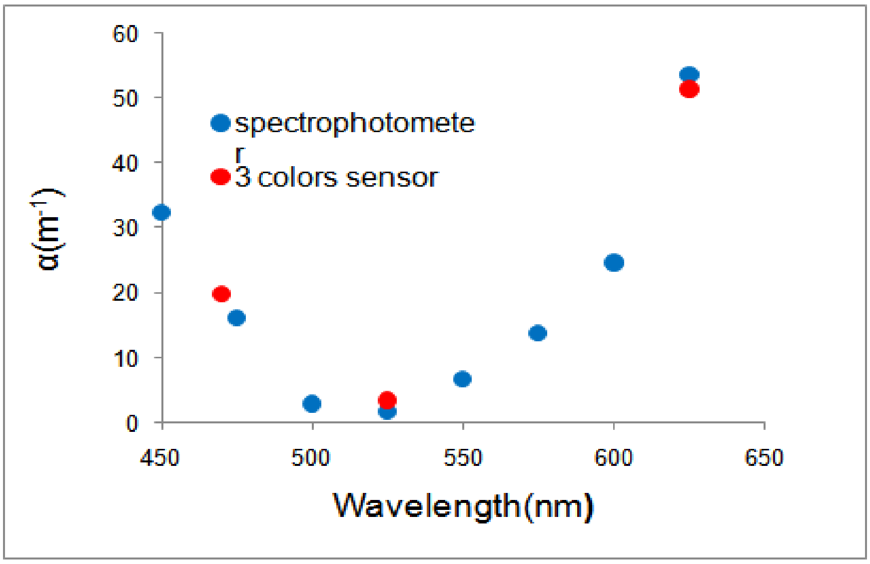

Figure 5: The absorbance of the prepared liquids measured by developed system and a spectrometer (SP-300)

Field experiments at a lake were carried out in the next place. Lake Senba of KairakuenParkin Ibaraki prefecture, Japanwas selected as experiment site. The generation of phytoplankton blooms in Lake Senba is a severe problem in summer season. It is conspicuous around south part of the lake. Figure 6 shows an example of the absorbance at the lake. The water is clear and we cannot recognize the phytoplankton bloom until April. However, the water becomes green gradually due to the phytoplankton bloom. The absorbance at blue is high compared with absorbance at green and red. We introduced simple index of absorbance for phytoplankton bloom as follows.

$$\Delta \alpha = \alpha_B - \frac{1}{2}(\alpha_R + \alpha_G)$$

Figure 7 show delta at the south part of the Lake Senba throughout the year. The phytoplankton bloom in Lake Senba increased in June. Then the city office used phytoplankton bloom removal equipment and the density of phytoplankton bloomdecreased in July. The density of phytoplankton bloomincreased again in August. The index of absorbance is coincident with visually observed data.

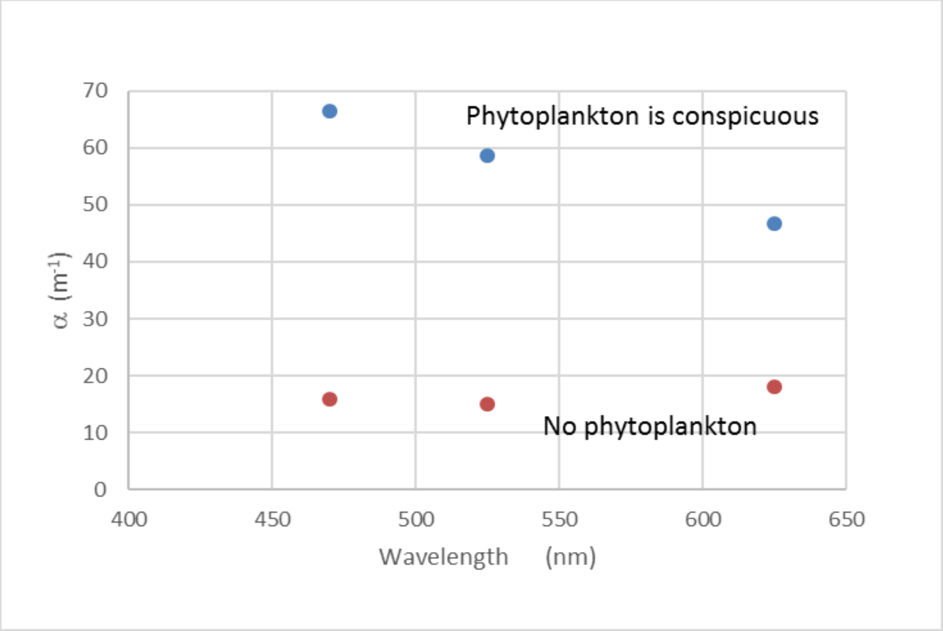

Figure 6: An example of the absorbances at the lake.

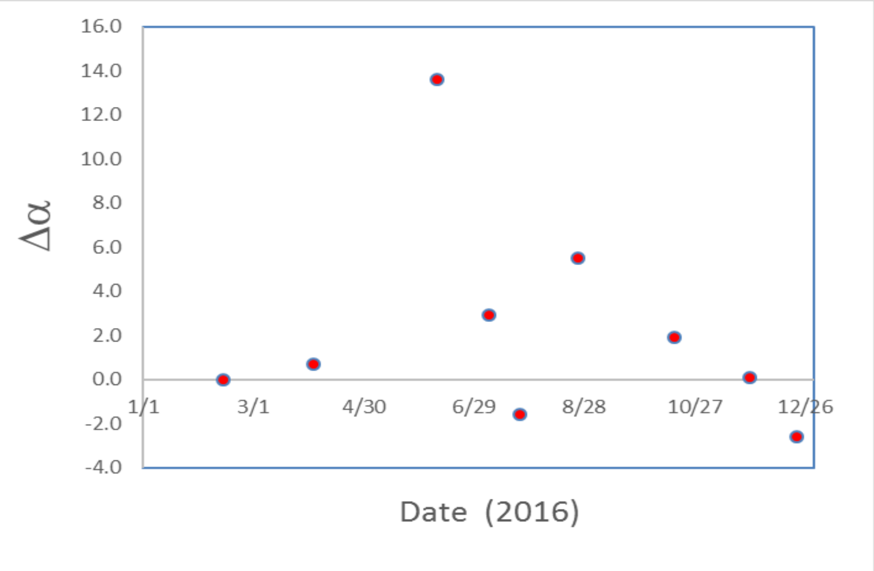

Figure 7: Delta at the south part of the Lake Senba throughout the year

IV. DEVELOPMENT OF SPECTROSCOPIC MEASUREMENT SYSTEM

To obtain more precise information of absorption, several commercial spectrometersare available. However,some of conventional spectrometers are not portable and they are expensive. Therefore,we developed a portable measurement system using a spectrometer module and a microcontroller. Figure 8 and 9 show the concept of spectroscopic measurement system and the photo. We scoop water from water surface and absorption spectrum of the water is measured in-situ. Water is poured into a transparent plastic cup and light source (white LED) and the spectrometer were put in opposite directions.

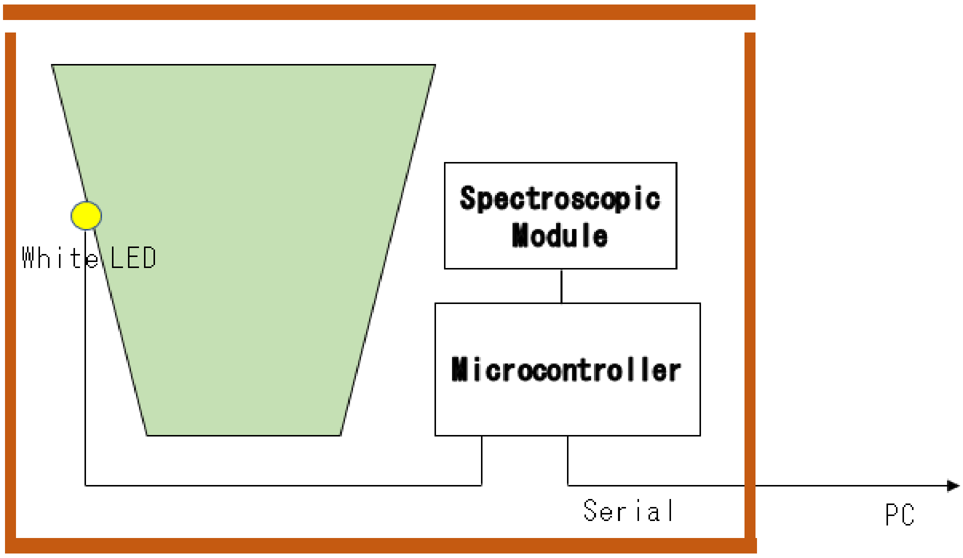

Figure 8: Concept of the spectroscopic measurement system

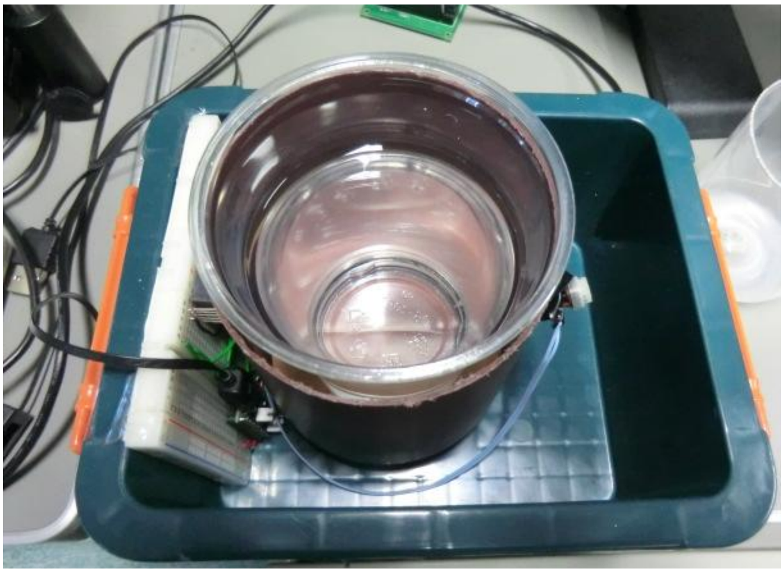

Figure 9: photo of the spectroscopic measurement system

Figure 10 shows the circuit of the system. Mini-spectrometer C10988MA-01 (Hamamatsu Photonics) was used. The spectral response range is 340nm to 750 nm. Number of pixels of spectrometer is 256 and the spectral resolution is 14nm. The R8C/M11A microcontroller was used controlling the system. The R8C/M11A is very small, however it has 10-bit A/D Converter and UART serial interface. The microcontroller gets spectroscopic data when the LED is ON and OFF and sends data to PC through serial communication.

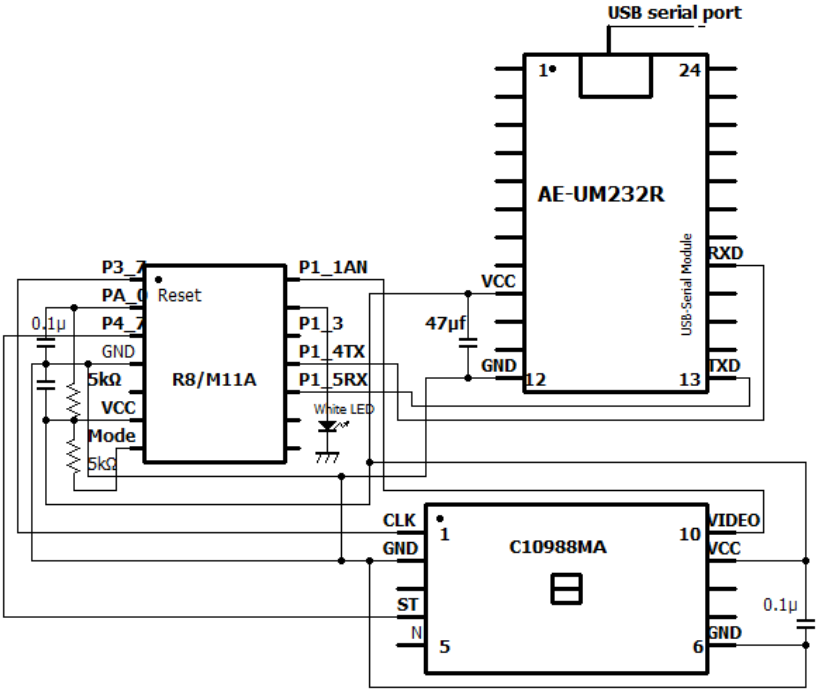

Figure 10: Circuit diagram of the spectroscopic measurement system

Figure 11 shows the flowchart of measurement. First, pure water is set in the plastic cup. A spectrum is measured when LED is on,$P_0(\lambda)$, and a spectrum is measured when LED is off, $P_1(\lambda)$. Then, target water is set. A spectrum is measured when LED is on, $P_2(\lambda)$, and a spectrum is measured when LED is off, $P_3(\lambda)$. $P_1(\lambda)$ and $P_3(\lambda)$ are spectrums of external light. $P_0(\lambda)$-$P_1(\lambda)$ and $P_2(\lambda)$-$P_3(\lambda)$ corresponds to spectrums of LED light which go through in the water. The logarithm of $P_2(\lambda)$-$P_3(\lambda)$ divided by $P_0(\lambda)$-$P_1(\lambda)$ corresponds to the absorbance of

target water.
$\alpha(\lambda)=\log((P2(\lambda)-P3(\lambda))/(P0(\lambda)-P1(\lambda)))/L$
where L is the distance between the LED and the spectrometer.

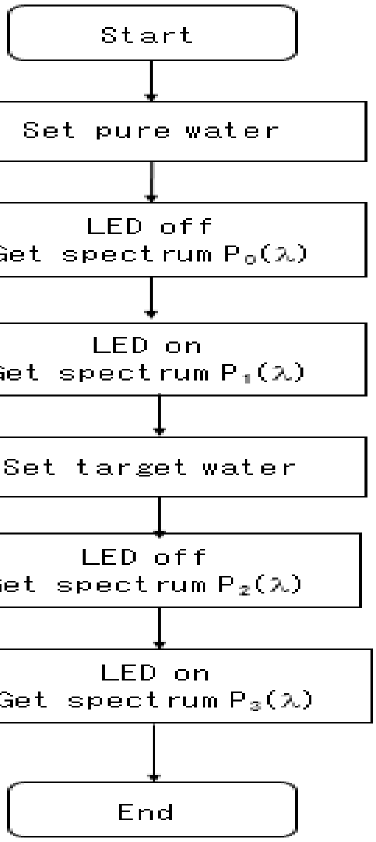

Figure 11: Flow diagram of the measurement system

Figure 12 shows the example of spectrums of target water and pure water. Figure 13 and 14 shows calculated absorbance of water of the Lake Senba. Water was sampled where the phytoplankton bloom is heavy (Fig.13) and weak (Fig.14) conditions. When the density of phytoplankton bloom is strong, the absorbance of blue is larger than that of green or red.

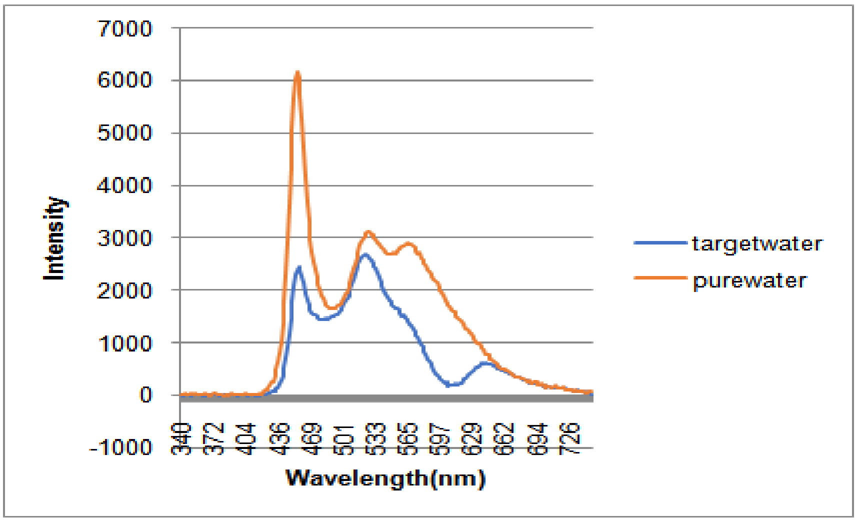

Figure 12: Example of spectrums of target water and pure water.

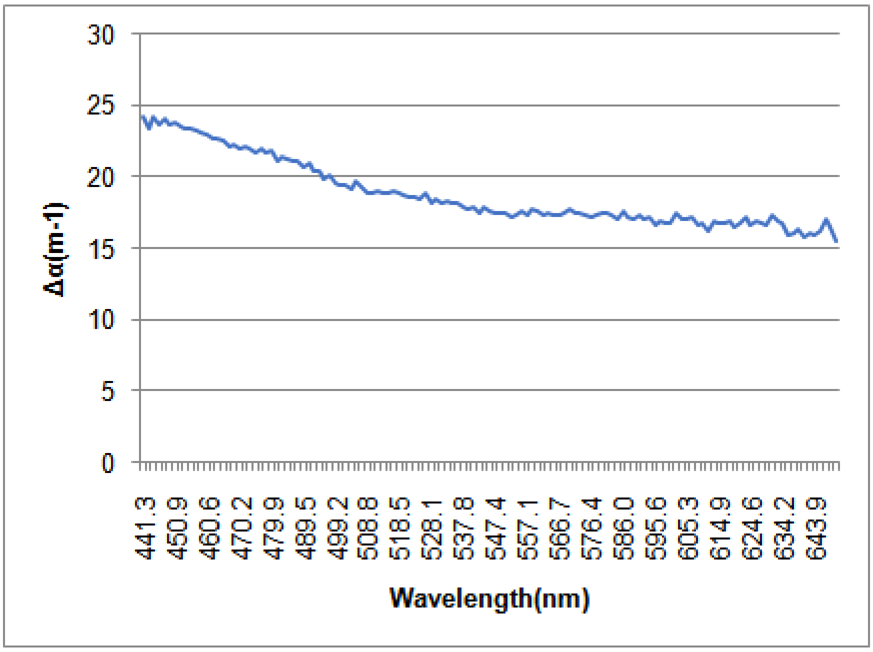

Figure 13: Calculated absorbance of water of the Lake Senbaunder heavy phytoplankton bloom

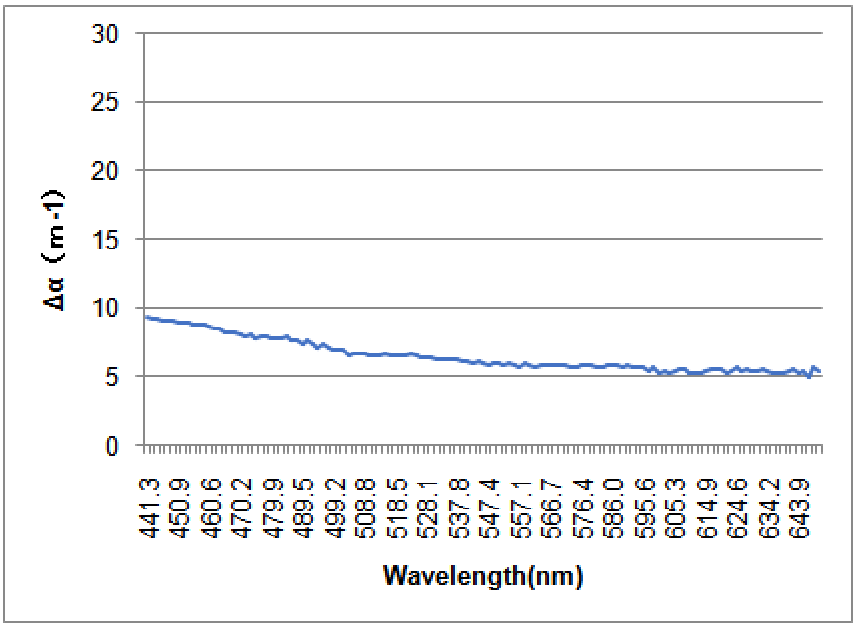

Figure 14: Calculated absorbance of water of the Lake Senbaunder weak phytoplankton bloom

V. Conclusion

In this paper, we proposed two types of portable water color measurement systems using microcontrollers. One is using three color LED and the system is put on the water surface. The other system is using spectrometer module and more detailed information of spectrum can be obtained. Fundamental experiment of present study conducted in laboratory and at Lake Senba. Data were collected from the phytoplankton blooms.

Three-color LED system is most suitable, when phytoplankton bloom is the major source of pollution and we can ignore other pollution sources. When we consider other pollution sources, the system using spectrometer module is most effective.

To promote the utilization of our system, we must consider some parameters of the system including cost, power consumption, portability, and data access. The price of Mini-spectrometer is about 100 $, but other components including microcontroller are relatively less expensive.

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Ping WANG, Yuko Ishikawa, D.D.G.L.Dahanayaka and Atsushi Minato, "Portable Water Color Monitoring System Using Microcontroller for Phytoplankton Bloom Measurement in Japanese Lake.“International Journal Of Modern Engineering Research (IJMER), vol. 08, no. 07,