A Simple Dissolved Oxygen Sensor using Low-Cost Visible Spectro Sensor

Tran Thi Ngoc Huyen, Tran Khac Duy, Nguyen Minh Trang, Luong Vinh Quoc Danh, Anh Dinh

Abstract— ***Dissolved Oxygen sensor is used mainly in aquaculture industries and environmental sectors to measure the concentration of oxygen dissolved in water. The level of dissolved oxygen in water strongly affects the growth of organisms in aquaculture. There are many methods to measure the concentration of dissolved oxygen in water including colorimetric, titrimetric, and polarographic. Newly-developed technique uses optical principle to measure the reaction of oxygen to the fluorescent dye and the concentration of oxygen is calculated based on the Stern-Volmer equation. This work develops a very simple optical sensor based on this principle but uses extremely low-cost, off-the-shelf optical components for detection. The heart of the sensor is the AS7262 6-Channel Visible Spectral ID Device made by AMS. The sensor was built and tested against the commercial devices made by Extech (Model 407510). Preliminary results show a promising device which is very low cost, simple, low maintenance, and easy to use in the field to support aquaculture industries and environmental agencies.***

Keywords—dissolved oxygen, sensor, visible spectrometer, low-cost sensor

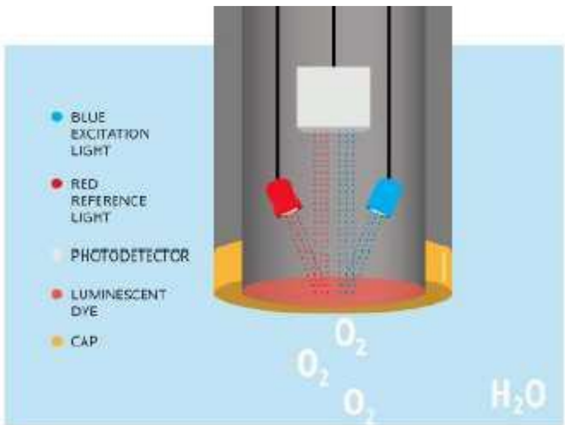
I. INTRODUCTION

Dissolved oxygen (DO) is the oxygen molecules dissolved in water and it plays a key role to maintain life in water. DO can also be considered as an indication of water quality. Not enough oxygen in water causes reduction in growth and may lead to death to adult and juvenile fishes [1]. There are many methods currently used to detect DO content in water [1,2]. The benchmark method is iodometric in laboratory and, of course, it is a complex detection process. The electromechanical method is based on redox reaction. Electrodes are used to detect the current generated from the reaction. This method is classified by the detection principle either polarographic or galvanic cell type. Many commercial available DO sensors based on these two principles are on the market [3,4]. However, most of them are expensive, requires skill operators, time consuming, and normally, they are not reusable, not mentioned the high maintenance cost. The last and recently-developed method is based on the optical principle. Fluorescent quenching is used in the case, including fluorescent lifetime detection and fluorescent intensity detection. This method has more benefits compared to the other two as it has faster response, low maintenance, no warm-up time, and lowdrift over time. Mechanism of the fluorescent quenching process follows the Stern–Volmer relationship:

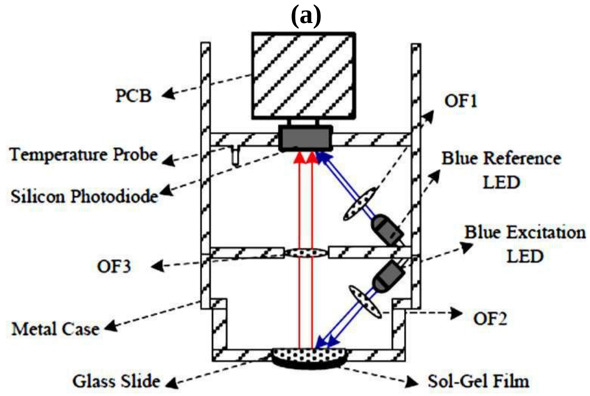
1 . | | (1)

where F0 denotes the fluorescence signal intensity of anaerobic water; F denotes the fluorescence signal intensity of the water samples; KSV denotes the Stern-Volmer constant; and |Q| denotes the concentration of quencher [5].

Fig. 1 illustrates the working principle and an example of the structure of the DO optical sensor. The cap of the sensor is submerged in the water. Dissolved oxygen penetrates into the probes and under the excitation of blue light on the luminescent dye, red light is emitted and the light is measured using photodiode after the light passing through a series of optical devices.



(a)



(b)

Fig. 1. (a) Cross section of an optical DO sensor [6], (b) an example structure of the optical DO sensor [5]

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Tran Thi Ngoc Huyen, Department of Electronics and Telecommunication Engineering, College of Engineering, Cantho University, Can Tho,Vietnam

Tran Khac Duy, Department of Electronics and Telecommunication Engineering, College of Engineering, Cantho University, Can Tho, Vietnam

Nguyen Minh Trang, Department of Electronics and Telecommunication Engineering, College of Engineering, Cantho University, Can Tho, Vietnam

Luong Vinh Quoc Danh, Department of Electronics and Telecommunication Engineering, College of Engineering, Cantho University, Can Tho, Vietnam

Anh Dinh, Department of Electrical and Computer Engineering, University of Saskatchewan, Saskatoon, Canada

As shown in Fig. 1, the main task in the detection is the measurement of the fluorescence signal intensity of anaerobicwater and of the water samples. This tedious light processing work involves optical grating and filtering in order to detect the glow of red. Traditional techniques to perform optical processing are complicated and expensive. Fortunately, newly-developed technology in MEMS and electronic circuits have reduced complexity, size, and cost of the detection of VIS spectrum. This work takes these advantages to design a simple DO sensor system at a very low cost.

II. SENSOR DESIGN

The proposed system consists of two main parts as shown in Fig. 2. Photograph of the designed prototype is also included in the figure. The first section is the sensing and the second is data collection. First, oxygen dissolved in water must penetrate to the enclosure through a semi-permeable membrane. The membrane allows oxygen atoms passing through and prevents larger compound such as H2O or others in the water to enter the chamber. As soon as O2 enters the enclosure, with the excitation of blue light on the fluorescent dye, red light will emit. The amount of red light is proportional to the oxygen concentration (quencher) as shown in the Stern-Volmer equation in the quenching process. The red light is to be detected by the visible (VIS) spectrometer.

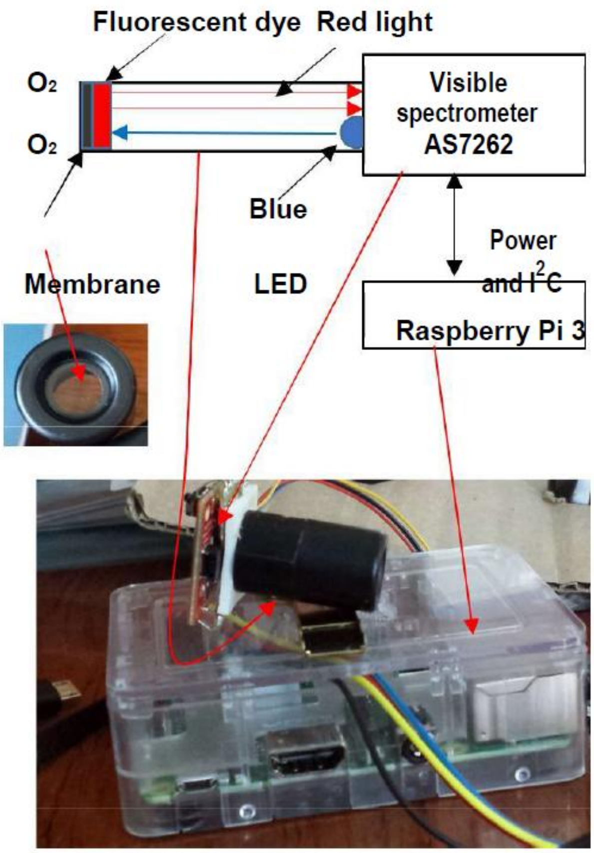


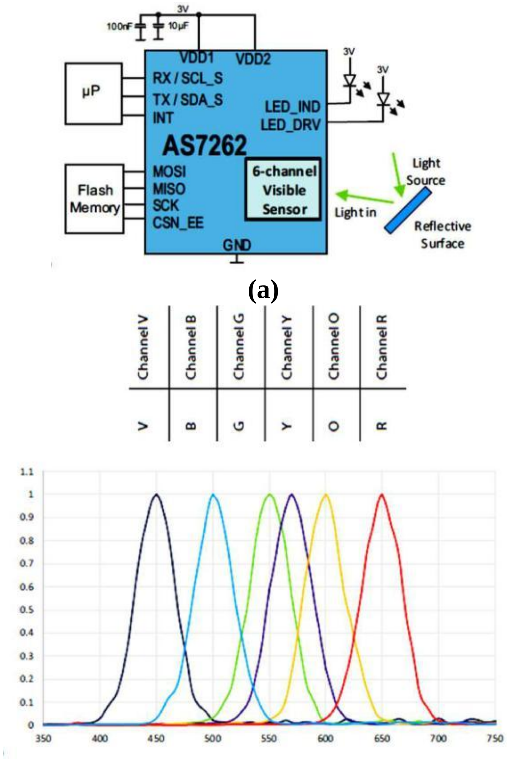
Fig. 2. System overview

The blue LED, OVS5MBBCR4, 0.48W, 465nm (460nm ~ 470nm), made by TT Electronics/Optek Technology is used in this design. This high brightness LED can be turned on or off to excite or stop the quenching process. There is also a whitelight LED on-board the spectrometer to be used on the same purpose as desired since there is blue light in the white spectrum.

An important agent used in this sensing probe is the fluorescent dye as the quenching process emits light. The chemical called Tris(bipyridine)ruthenium(II) chloride is used in this senor. This coordination compound has the formula [Ru(bpy)3]Cl2 [7]. This red crystalline salt is used as the fluorescence indicator because of its highly emissive metal-to-ligand charge-transfer state, long lifetime, and strong absorption in the blue-green region of the spectrum [8]. These characteristics of this salt well suit to the high-brightness blue LED in this design.

The most important component in the sensor is the compact, low cost, advanced technology system-on-chip spectrometer, the AS7262 made by AMS [9]. This highly integrated device delivers 6-channel multi-spectral sensing in the visible wavelengths from approximately 430nm to 670nm with full-width half-max of 40nm as shown in Fig. 3. An integrated LED driver with programmable current is provided for electronic shutter applications. Control and spectral data access is implemented through either the I²C register set, or with a high level AT Spectral Command set via a serial UART

In this design, the I²C communication between the spectrometer and the Raspberry Pi is used for controlling the spectrometer and data collection. A 3.3V DC power supply to the sensor is provided by the Raspberry Pi.



(b)

Fig. 3. The visible spectrometer AD7262: (a) block diagram, (b) its typical optical characteristics (normallized intensity versus 6 color spectrums) [7]

Raspberry Pi (RP) is a common single board computer. The RP has enough computing power and peripherals for many practical applications including embedded systems. In this sensor prototype, the third model of RP is used to provide power to the sensor and establish communication link to the AS7262. Every second, the VIS spectrometer AS7262 sends 3 sets of 6 numbers representing the amplitude of 6 colors in the VIS spectrum. The RP is programmed (in Python) to receive and save data into a file (in Exel format) while the sensor is in operation. Data files are then transferred to a computer for viewing and processing.

III. EXPERIMEN RESULTS

The prototype was built and tested against the Heavy Duty Dissolved Oxygen Meter DO meter (Model 407510) made by Extech Instruments (USA). Data collected from the measurements are post-processed to calculate the concentration of oxygen dissolved in the samples. The post-processing includes determining the relationship between the oxygen concentration with the light intensity captured by the spectrometer (i.e., find the Stern-Volmer coefficient). As shown, the KSV is a constant since the relationship between F0/F and concentration of the quencher is linear.

Fig. 4 displays the measurement results of the red light intensity from the spectrometer. The AS7262 provides the value of the 6 channels in counts/μW/cm^2 with an accuracy of ±12%. With the presence of oxygen in the chamber, there is no red glow until the blue LED is turn on to excite the process. As soon as the blue LED is turn off, the fluorescent dye stops illuminating the red light. This figure also shows there is not much different in the light intensity when the amount of fluorescence dye is double in the probe. This proves that the amount of dye does not play an important roles and the reduction of the dye is minimum for each measurement. This observation concludes that the frequency of probe maintenance is very low compared to the refill of chemical in the polarographic or galvanic cell type DO sensors.

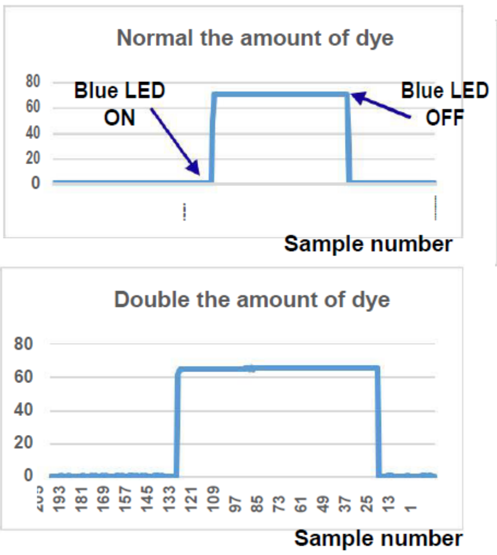


Fig. 4. Red light intensity in a 7.8mg/L DO water for two different amountsof Tris(bipyridine)ruthenium(II) chloride in the probe

Fig. 5 shows an example of the data collected on the measurements on 3 different samples: air, contaminated water with a DO of 6.3mg/L, and normal water with a DO of 7.6mg/L. This is the average of 3 measurements of red light intensity on 3 different DO concentrations.

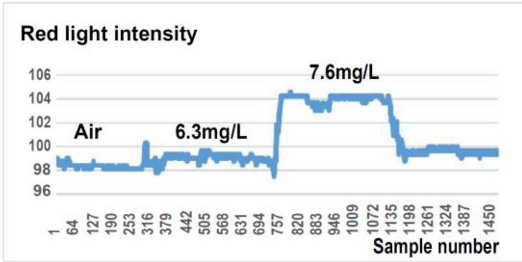


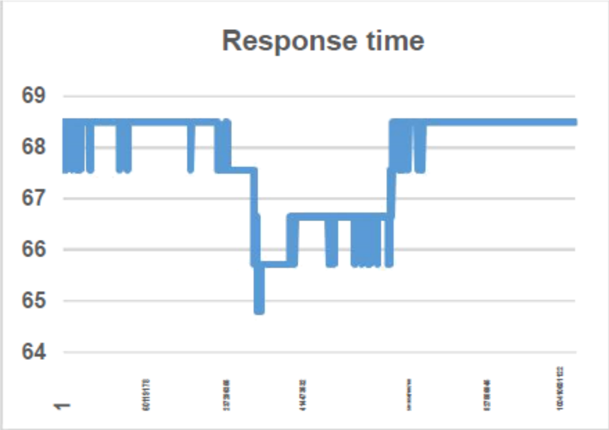
Fig. 5. Average red light intensity in air, 6.3mg/L DO contaminated water, and 7.6mg/L normal water

The post data processing was performed on multiple measurements on 3 different amounts of chemical in the probes, 3 different level of DO concentrations, and 3 measurements on each combination. The results were compared with the measurement of the Extech and the average reading difference is 88%. The data processing is not described here for simplicity. Note that the true intensity of the red light is not important as the calculation to estimate the DO concentration depends on the ratio between two intensities (F0/F), not on the amount of red light emitted from the quenching process.

In general, optical sensor has faster response compared to other DO measurement methods. Fig. 6 shows the response of the sensor when it is switched from measurements between two liquids with different dissolved oxygen levels. This should be compared to minutes to stabilize the response in the galvanic type sensor. Long term stability was also tested to check the drifting of the sensor over time. The display in Fig. 6 shows a 40-minute run with the intensity of the red light for a 7.2mg/L oxygen in water. The change is very small and stable over time.

IV. DISCUSSION AND FUTURE IMPROVEMENT

The proposed DO optical sensor is very simple, compact, fast response, and very low cost as the design takes advantages of the newly developed system-on-chip visible spectrometer. Experimental results show a comparable to the commercial DO sensor. One of the most benefits of this optical sensor is the low maintenance and ease of use. High maintenance cost is one of the hurdles preventing the popular use of DO sensors from the fish farmers. In the future, the RP should be replaced by a tiny embedded system to perform data collection, processing, and display to minimize size and cost while reducing power consumption. Self-calibration should also be included. The calculation of the DO concentration requires further improvements as the amount of oxygen dissolved in the water depends on other factors such as temperature, pressure, and salinity. Pressure and temperature sensors must be incorporated into the real sensor to obtain higher accuracy.



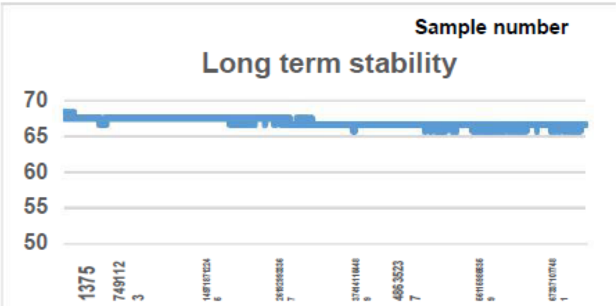


Fig. 6. Response time and long term stability Sample number

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