Sensors and Actuators B 233 (2016) 674–683

Contents lists available at ScienceDirect

Sensors and Actuators B: Chemical

journal homepage: www.elsevier.com/locate/snb

Design and development of portable opto-electronic sensing system for real-time monitoring of food fermentation

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ARTICLE INFO

Article history:
Received 15 November 2015
Received in revised form 21 April 2016
Accepted 25 April 2016
Available online 26 April 2016

Keywords:
Opto-electronic sensor
Food fermentation
pH
Dissolved oxygen
Minimal invasive

ABSTRACT

The paper presents an optical based measurement system to monitor the fermentation process of food samples, such as raw milk, pasteurized milk, curd, grape juice and batter. The microbial growth during the fermentation and its effects in changing the parameters such as pH, dissolved oxygen, optical density and fluorescence are observed continuously by using minimal invasive optical sensing system. The sensing membranes for pH and dissolved oxygen are prepared using sol-gel technique and attached at an inner wall of a single-cell transparent container. The opto-electronic system is constructed to hold a single-cell transparent container along with light sources, detectors, signal processing circuits, computational and display unit. The performance characteristics, such as stability, response time and reproducibility are verified before it has been applied for food fermentation analysis. The developed optical sensor system shows the maximum relative error rate of 3.98% and a minimum of 0.21% for the pH measurement and for the dissolved oxygen measurement the relative error rate is observed between 0.36% and 3.75%. The results are found comparable and the proposed simple and cost effective system may be considered to monitor the food grades at the household level.

1. Introduction

Continuous monitoring of microbial growth characteristics is very essential and considered as the backbone in various fields, among others-food industry, agriculture, genetic engineering, medicine, and environmental biotechnology [1]. Especially, in the food industry, starting from mixing of the raw materials for the preservation of prepared food, monitoring the growth of microbes and their transformation activity is very much important as microorganisms play the vital role in both production and spoilage [2]. The various organisms, such as bacteria, yeasts and moulds are responsible and should be monitored continuously to preserve the quality and safety of the food. In the fermentation process and for the proliferation of microbial cell activity several factors, among others temperature, water activity, pH, dissolved oxygen are involved [3]. In general, the better food processing methods, escalation rate, metabolic actions of microorganisms, pH and dissolved oxygen are the parameters to be continuously monitored in order to endorse the food quality [4].

In a bio-process environment, the sensing of pH and dissolved oxygen can be made using the technologies of glass electrode, ion sensitive field effect transistors, amperometric, potentiometric and optical sensors [5,6]. In these methods, electrochemical sensors are used as invasive measurement and found to contaminate the bio-samples [7]. The optical sensors are the preferred method for biological process as it proved as a non-invasive and non-destructive measurement and it also does not need frequent calibration [8]. The integrated optical sensors that offer both pH and dissolved oxygen are considered as an ideal solution for the fermentation processes. A number of useful research papers pertinent to opto-electronic monitoring system with integrated sensors for the fermentation reactor columns, have been published over the years [9–15]. Also, more numbers of commercial bio-reactors integrated with an optical measuring system are available; however, all such methods are not economically liable and larger in size [16]. The opto-electronic sensor system is based on light interacting principle, including absorbance, fluorescence and reflectance [17]. The characteristics, such as pH and dissolved oxygen are measured through activating the fluorescence chemical dyes with appropriate light illumination and optical density of fermented samples is based on the scattering of light [18–21]. The sensor patches based opto-electronic instruments are available. However, insignificant numbers

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http://dx.doi.org/10.1016/j.snb.2016.04.143
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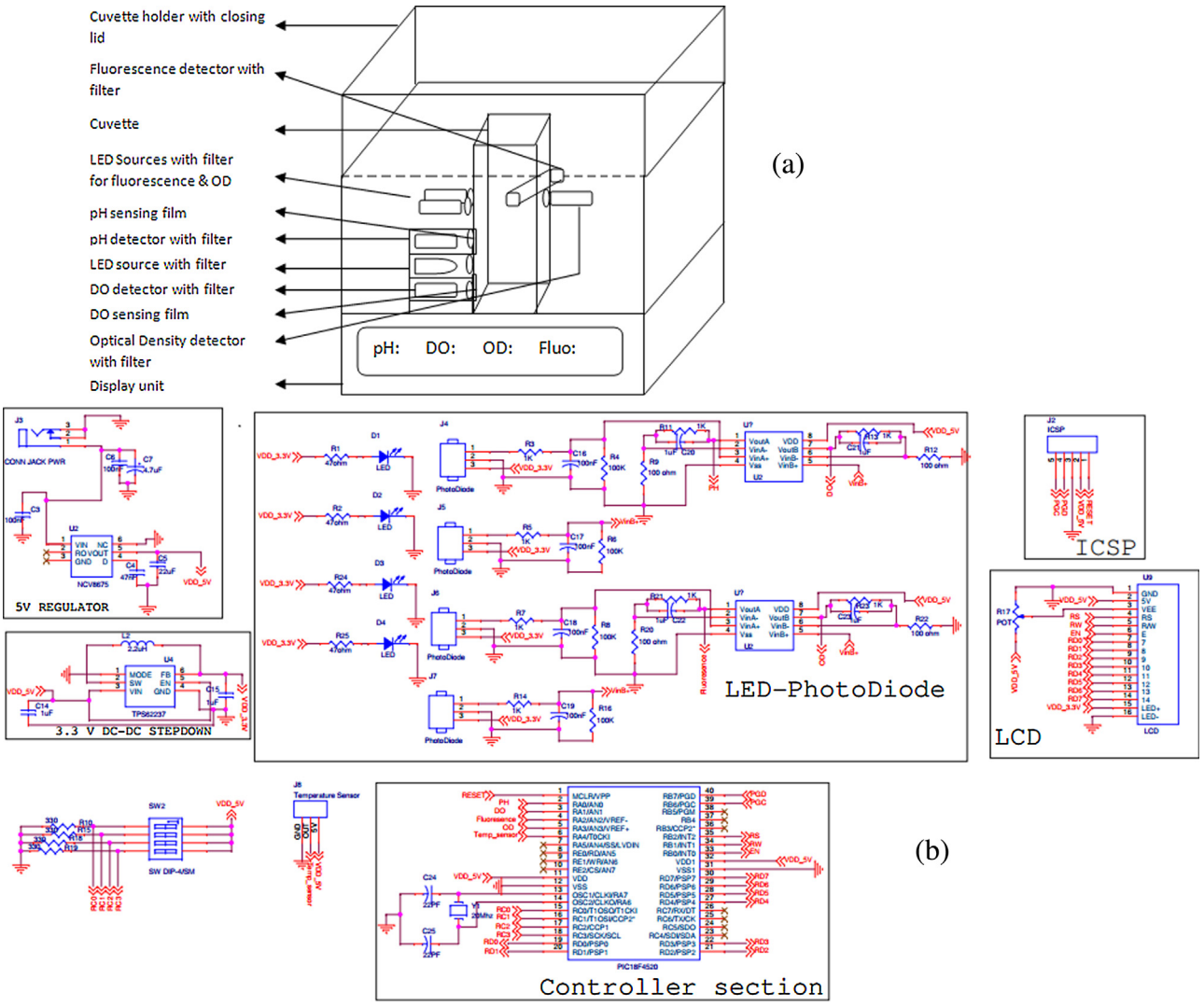

Fig. 1. (a) Experimental setup of single-cell container with opto-electronic components (b) PCB layout for the electronic circuitry.

of works have been carried out for real-time food fermentation monitoring. Further, no field deployable, real-time and cost-effective portable opto-electronic instruments are suggested as a house-hold product to test the quality of food samples. The objective of this paper is to design a portable opto-electronic system to monitor the food fermentation process by measuring the parameters, such as pH, dissolved oxygen, optical density and fluorescence in a straight-sided transparent small container (cuvette). The growth rate of microorganisms is observed by continuously monitoring the fluorescence and optical density of the medium. The disposable pH and dissolved oxygen sensing membranes are made as a thin dot using fluorescent dyes, such as Carboxyfluorescein and Ruthenium complex respectively. The signals are calibrated by using an in-built microcontroller and programmed to display the concentration of measuring parameter directly. The sensor characteristics, such as physical and photo-chemical stability, response time, sensitivity and reproducibility are evaluated. The proposed sensor is continuously applied to monitor the changes in the food samples, including milk, curd, grape juice and batter for the significant period of time. The advantages of this work are being easily operable, pre-calibrated, cost-effective and a portable that can be used as a house-hold instrument.

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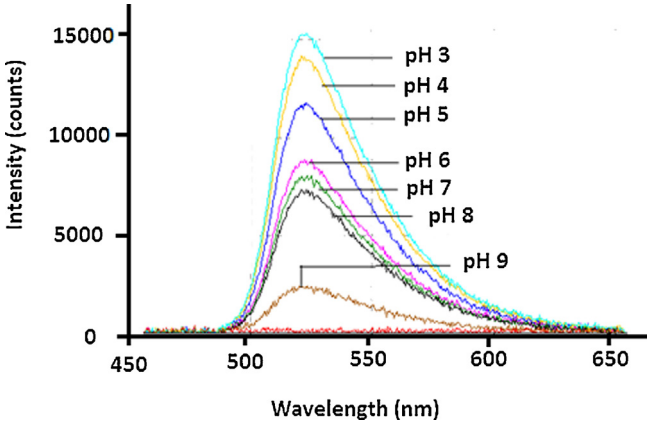

Fig. 2. Fluorescence spectrum of pH sensing membrane.