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Colorimetric fiber optic probe for measurement of chemical parameters in surface water

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ABSTRACT

In this paper a novel fiber optic chemical sensor is proposed with possibility of measuring several chemical parameters using simple structured and low-cost colorimetric probe with high precision. Proposed sensor is based on user oriented and intuitive HSV color model. Concentrations of the orthophosphate, nitrite, sulfate, hexavalent chromium (Cr (VI)) and total chlorine obtained with laboratory analysis were compared with concentrations obtained with proposed sensor in order to demonstrate the effectiveness of the sensor. Relative differences in determined concentrations ranged from 2.31% for sulfate to 6.20% for total chlorine. Implemented sensor with its advantages such as low cost, simple use, reliability and small size, could be used for monitoring of water quality. Sensor is applicable for laboratory work, under controlled conditions, and could be used as a replacement for standard laboratory equipment as an effective, precise, repeatable and low-cost solution.

1. Introduction

Conventional techniques in laboratory practice are characterized by precision, accuracy, sensitivity and selectivity. Collection of water samples followed by sample preparation and laboratory analysis is complicated and expensive [1]. Therefore, cheaper and faster alternatives for monitoring of surface water are required. With appropriate configuration, calibration and fiber feature, fiber-optical sensors (FOS) can have the same accuracy as conventional methods [2].

The first fiber-optic chemical sensor was developed in 1970s. Ten years later, fiber-optic sensors were used for environmental monitoring and immediately became commercial devices for measurement of pH, dissolved oxygen and temperature in water samples [3–8]. FOS present effective measurement techniques, attractive for use in a wide variety of application areas. Real-time measurements require development of rapid FOS. Therefore, FOS has been developed for detection of various chemical parameters in surface and wastewater samples [9], such as: sulfide [10], toluene [11], chlorine [12], nitrate [13,14], nitrite [14], ammonia [15] and others.

FOS can be used in chemically aggressive environments, possess high mechanical and corrosion resistance, require no electrical power at the sensing point, and are immune to electromagnetic interference. Those sensors are lightweight, miniature, inexpensive, sensitive, and reliable; employ accurate techniques with remote sensing capability and possibility to measure two or more parameters in the same time and to provide real-time data [4,5,16,17]. Utilization of sensors can be affected by changes in the environment and the external influences may cause their deformations [18].

In this paper, fiber-optic chemical sensor based on HSV color model was developed and calibrated for measurement of orthophosphate, nitrite, sulfate, hexavalent chromium (Cr (VI)) and total chlorine in surface water samples. Mentioned chemical parameters have negative impact on chemical and ecological status of environment. High concentration of phosphorus causes eutrophication [19], chlorine is used for disinfection of drinking water and during this process trihalomethane could be generated [20]. Nitrite and hexavalent chromium are very toxic to aquatic species [21]. Sulfate anions as the weak Bronsted Lowry bases indicate the acidification in water body [22]. In river water samples, concentrations of chemical parameters were measured by standard methods using UV/vis spectrophotometer and compared with the value of concentration measured by fiber-optic chemical sensor based on HSV (Hue (H), Saturation (S), and Value (V)) color model in order to prove the effectiveness of optical sensor measurements. Changes of H, S and

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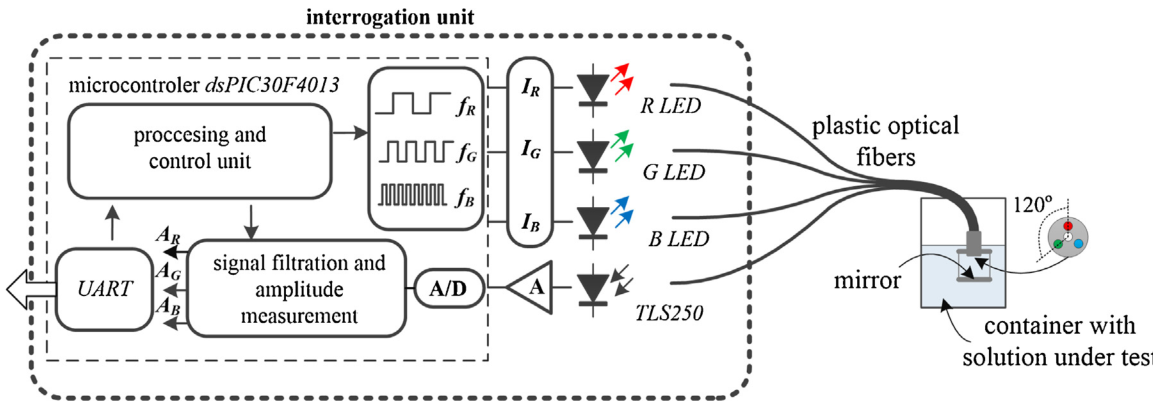

Fig. 1. Block diagram of the implemented sensor. (For interpretation of the references to color in the text, the reader is referred to the web version of this article).

V parameter may be linked with the changes in concentrations of selected chemical parameters in the water samples. Further, device for laboratory use can lead to development of instrument for on-line monitoring, which will be precise, repeatable, simple to use and cheap.

2. Principle of operation of the proposed sensor

The fundamental operating principle of the proposed sensor is the absorption of light. When the light passes through a liquid, certain wavelengths will be transmitted while others are absorbed depending on the color of the tested liquid. The block diagram of the implemented sensor is presented in Fig. 1.

The way the proposed sensor determines color is based on principle of additive RGB (red, green and blue) color model. Interrogation unit consists from three LEDs (Light Emitting Diodes) emitting red (R), green (G) and blue (B) components of the visible light, and one photodetector TLS250. The peak wavelengths of R, G and B LED are located at $\lambda_R = 634$ nm, $\lambda_G = 516$ nm, and $\lambda_B = 466$ nm, respectively. Light from LEDs is inserted into three plastic optical fibers which lead the red, green and blue component to the tested liquid. Optical fibers with 1 mm diameter are used. A mirror is mounted below the optical fiber ends. Light emitted from the optical fibers passes through the tested liquid and reflects from the mirror as presented in Fig. 2a. Reflected light passes once again through the liquid and goes toward fourth optical fiber. Fourth optical fiber collects the portion of the light reflected from the mirror and leads it to the photodetector TSL250 located at interrogation unit. Signal from photodetector is amplified and led to 12 bit A/D converter. Interrogation unit uses frequency domain multiplexing. Red, green and blue LEDs are excited at different frequencies ($f_R = 1.125$ kHz, $f_G = 2.25$ kHz and $f_B = 4.5$ kHz). In this way detection of the reflected signal is achieved with only one photodetector and three bandpass filters. Additionally, frequency domain multiplexing provides much faster response of the sensor in comparison to time domain multiplexing. Red, green and blue components after A/D conversion are separated by digital IIR filters on the microcontroller dsPIC30F4013. Filters are implemented as 8th order bandpass Butterworth filters with the cut-off frequencies around LEDs modulation frequencies.

3. Calibration and sample preparation

Fig. 2b presents implemented colorimetric fiber optic probe. Sensor is calibrated using distilled water. When submerged into distilled water the response of the sensor is adjusted so it corresponds to the white color in RGB color space. For the purpose of easier and more intuitive interpretation of the measurement results response of the sensor in RGB color space is converted in HSV user-oriented cylindrical color space [23–26]. Finally, as results of measurement using proposed sensor three parameters are obtained: Hue or *H* parameter, Saturation or *S* parameter and Value of *V* parameter.

Hue or *H* parameter is a color attribute associated with the dominant wavelength in a mixture of light waves. Thus hue represents the dominant color as perceived by an observer; when an object is said to be red, orange, or yellow the hue is being specified [24]. Hue is usually represented with a color wheel and thus has values ranging from 0° to 360°. Saturation or *S* parameter refers to the relative purity or the amount of white light mixed with a hue. The pure

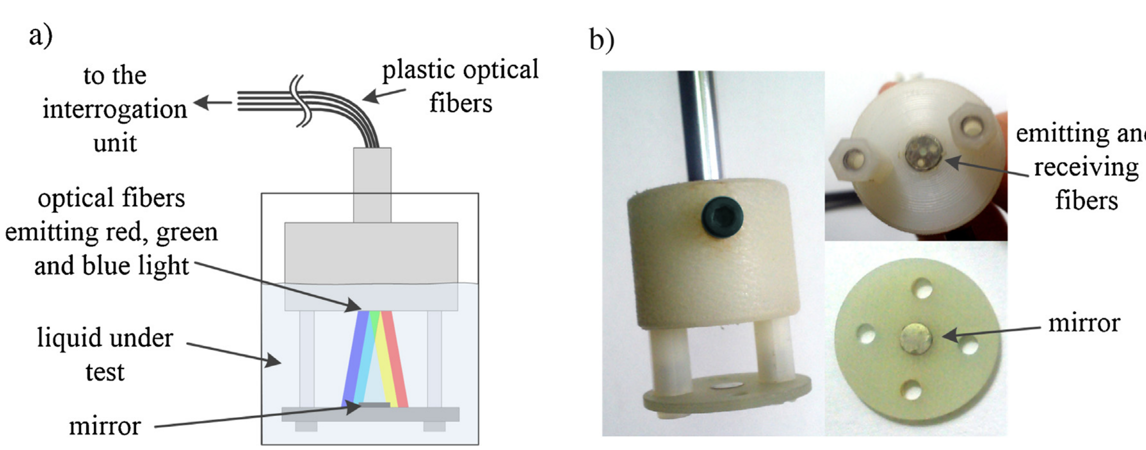

Fig. 2. (a) Principle of operation and (b) implemented sensor.