Polluted Water Measuring Using a Novel Optical Sensor System

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Key words: optical sensor, total suspended solids, algorithm, water pollution.

SUMMARY

A new multispectral optical sensor system has been designed and developed for measuring total suspended solids (TSS) concentration in polluted water. New algorithm was developed to correlate pollutant concentration and the scattered radiation. The optical sensing system has been designed for measuring scattered radiation from water samples. In this study two infrared LEDs (890 and 875nm) are used as sensing emitters in case (1), two visible LEDs (626 and 660nm) are used as sensing emitters in case (2) and one silicon photodiode is used as detector in both cases and two convex lenses are used for focusing the radiations, also an electronic circuit was designed. The sensors were calibrated for measuring total suspended solids concentrations between the range of 110 and 500 mg/l. The results showed a good correlation between the radiation values and the total suspended solids TSS concentrations in all cases. The accuracy is high with R^2 value of 0.99 in both cases and the root mean square error (RMSE) were 9.38 mg/l in case (1) and 8.77 mg/l in case (2).

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1. INTRODUCTION

Water pollution has become increasingly critical in this present-day, whether in the developed or the developing countries. Remote sensing technique is widely used to monitor the problems. Total suspended solids TSS in the water pollution can be detected by a number of remote sensing and optical sensing techniques which involve light interaction with the medium under investigation. Remote sensing of water substances has been proven to be a very useful tool for the monitoring of rivers, estuaries and coastal waters. Suspended particles (total suspended solids concentration TSS) can play an important role in ocean optical properties, including the spectral reflectance, because such particles can be abundant in seawater, they scatter light efficiently owing to their high refractive index relative to the water [Wozniak and Stramski, 2004]. The objectives of this work are: (i) to design a prototype of the multispectral optical sensor system for real-time measuring of the pollutant (TSS), (ii) to develop an algorithm to correlate the total suspended solids concentration with the scattered radiation.

2. OPTICAL SENSOR SYSTEM

The multispectral optical sensor systems can be used for monitoring the water content. Visible to infrared optical sensor provided information on the water content of the sensor system [Ceccato, et al., 2001]. The optical sensor system has been designed for measuring the scattered radiation by using two types of LED's as sources and only a silicon photodiode was used as detector, i.e. (i) two infrared light-emitting diodes LED's (890 and 875nm), (ii) two visible LED's (626 and 660nm). Two convex lenses were use to focus the radiations. An electronic circuit was designed to perform the algorithm implementation and standard polluted samples were prepared for calibration of the sensor between the range of 100 and 500 mg/l. The scattered radiation was measured in terms of the output voltage of the photodiode of the sensor system and the readings were measured using a multimeter. Figure (1) shows the diagrammatic design of the optical sensor system. Figure (2) shows the prototype system of the optical sensor.

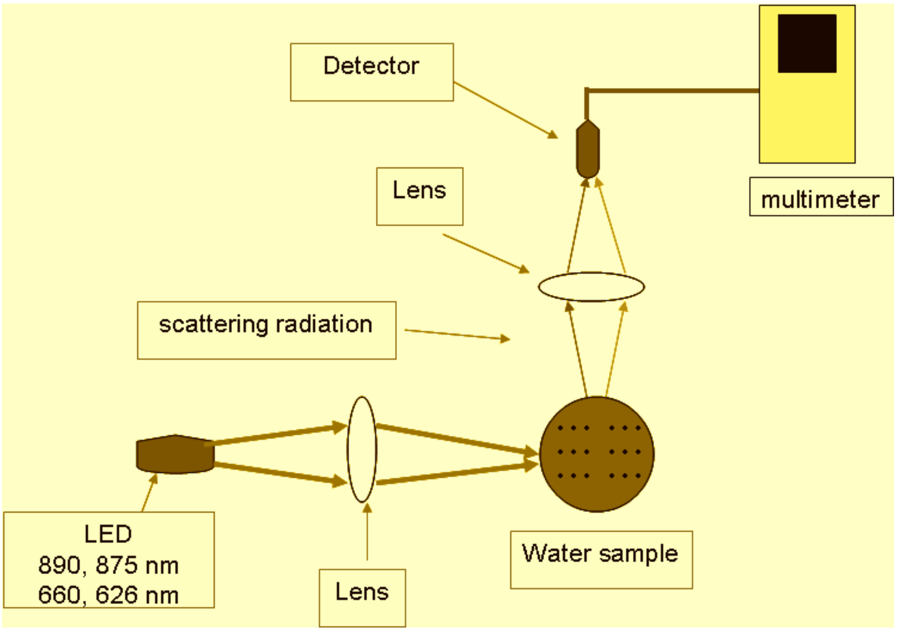

Figure 1. Diagrammatic design of the optical sensor system.

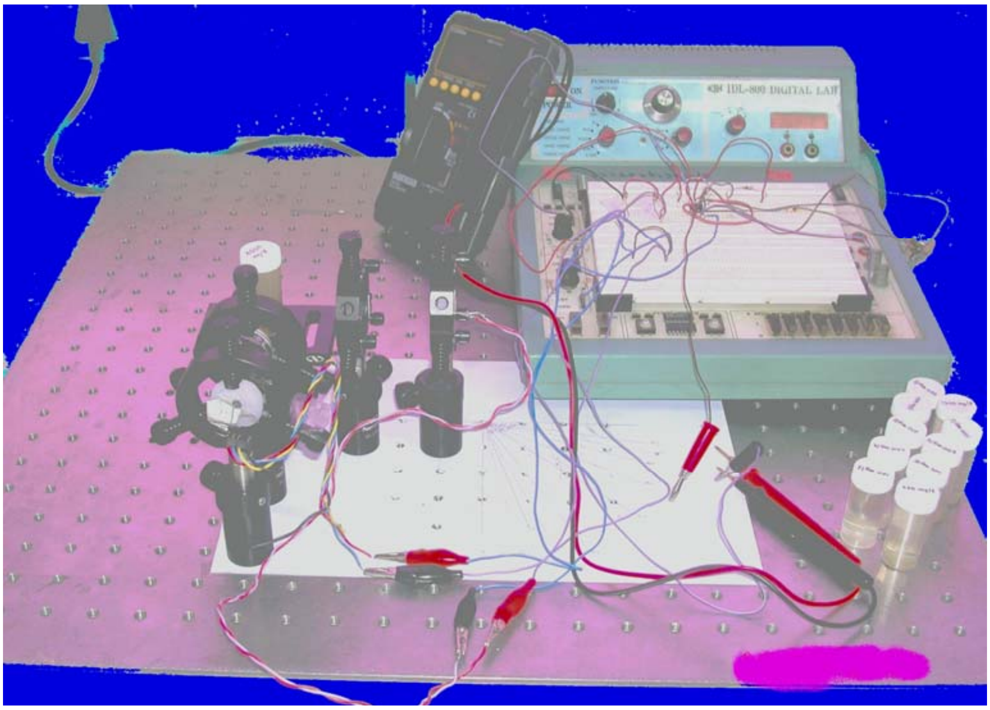

Figure. 2 Prototype system design of optical sensor.

3. NEW ALGORITHM

A new algorithm was developed for measuring and mapping water pollution. The developed algorithm was based on the spectral reflectance that depends on the inherent optical properties IOP_s of the water. The spectral reflectance R_{sr}, is given by

$$R_{sr}(\lambda) = 0.33\left(\frac{b_b(\lambda)}{a(\lambda)}\right) \qquad \text{...} \quad (1)$$

where λ is the spectral wavelength, $b_b(\lambda)$ and $a(\lambda)$ are the backscattering and absorption coefficients respectively [Morel, and Prieur, 1977].

The relation of polluted water in term of suspended particles with the detected radiations was derived as

$$TSS = \alpha_0 + \alpha_1\varphi_1 + \alpha_2\varphi_2 + \alpha_3\varphi_1\varphi_2 + \alpha_4\varphi_1^2 + \alpha_5\varphi_2^2 + \alpha_6\varphi_1^2\varphi_2 + \alpha_7\varphi_1\varphi_2^2 + \alpha_8\varphi_1^2\varphi_2^2 \quad \text{.....} \ (2)$$

where
TSS = total suspended solids concentrations.
φ_1=detected radiation (LED λ =890nm or λ =660nm).
φ_2=detected radiation (LED λ =875nm or λ =626nm).
α_i = coefficients, with i =0,1,…. were determined empirically.

4. ANALYSIS AND RESULTS

In case (1) when the infrared light-emitting diodes LED's (890 and 875nm) were used, the level of the photocurrent was linearly proportional to the pollutants (total suspended solids) concentration as shown figure (3). Figure (4) shows the relationship between the estimated total suspended solids TSS and the measured TSS concentrations for the infrared LED's.

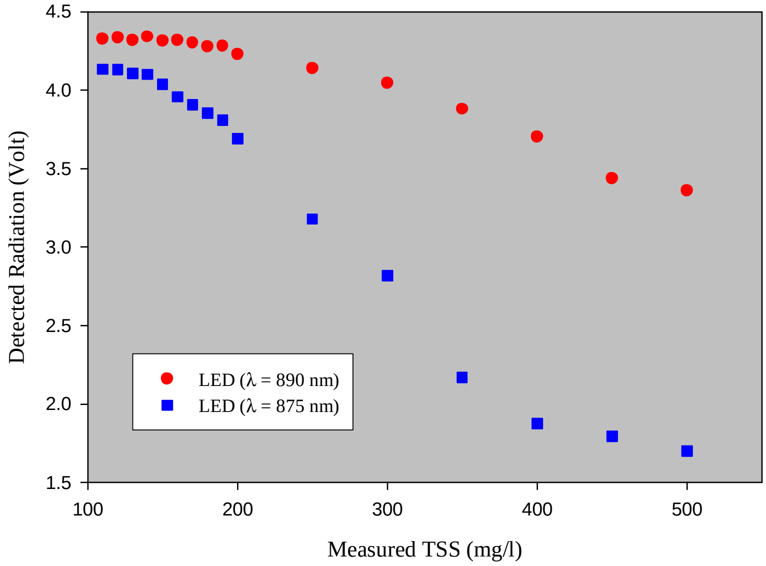

Figure 3. Measured TSS and the detected radiation for infrared LED’s.

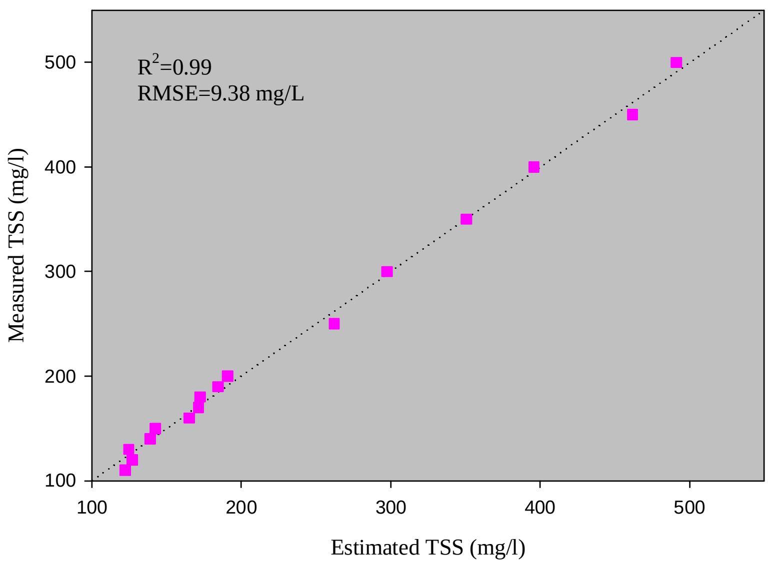

Figure 4. Estimated TSS with measured TSS for infrared LED’s.

In case (2) the visible light-emitting diodes LED’s (660 and 626nm) were used, the level of the photocurrent was linearly proportional to the pollutants (total suspended solids) concentration as shown figure (5). Figure (6) shows the relationship between the estimated total suspended solids TSS and the measured TSS concentration for the visible LED’s.

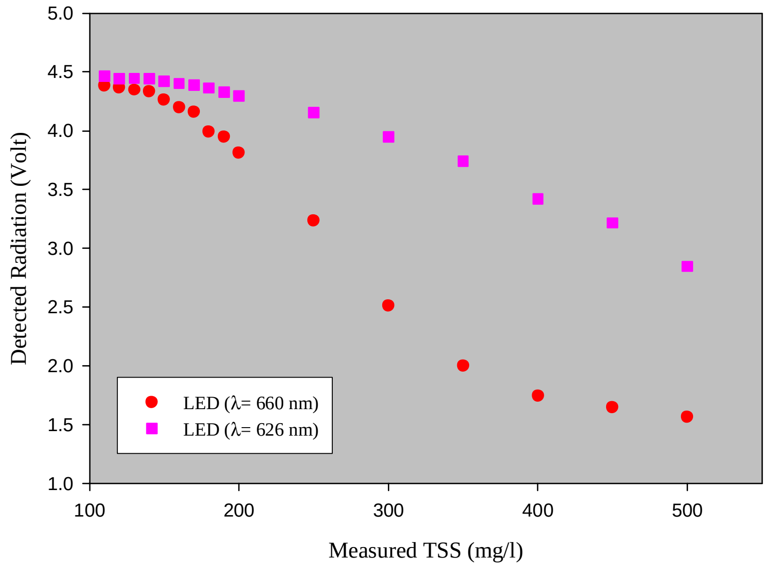

Figure 5. Measured TSS and the detected radiation for visible LED's.

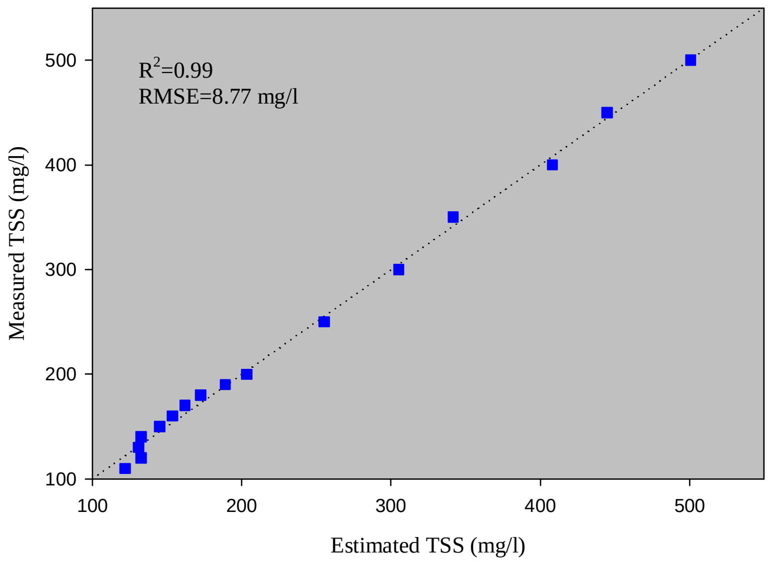

Figure 6. Estimated TSS with measured TSS for visible LED's.

The results show that for both cases, the newly developed algorithm produced a high degree of accuracy with the correlation coefficient R^2 of 0.99, and the root mean square error (RMSE) were 9.38 mg/l in case (1) and 8.77 mg/l in case (2).

5. CONCLUSIONS

A new developed optical sensor system produced a high degree of accuracy with the correlation coefficient (R^2) of 0.99 in the both cases and the root mean square errors were 9.38 mg/l in case (1) and 8.77 mg/l in case (2). This study has proven that the visible LED's sources were better than infrared LED's. This new methodology is very useful for measuring the water pollution levels. The developed algorithm was applied to optical sensor data and the results were encouraging. The newly optical sensor provides water pollution level information which can be used by many sectors such as tourism, environmental department, public sectors and others related sectors.

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