A transmittance and fluorescence meter for environmental monitoring

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Abstract

We describe here the design, laboratory implementation and performance of an inexpensive yet reliable beam attenuation meter (transmissometer) for coastal ocean environmental monitoring. In its final operational form, this instrument is anticipated to be capable of measuring chlorophyll fluorescence as well. Given that the relevant parameters - water clarity, algal concentration - are indicators of coastal ecosystem health, low-cost optical instruments emerge as valuable tools for activities such as coastal engineering, fish-farming and water quality monitoring in recreation areas.

Keywords: ocean optics; optical instruments; environmental monitoring; ocean technology.

1. INTRODUCTION

The use of optical instruments for monitoring the state of coastal waters has emerged as a common practice during the last decade [1],[2]. It is achieved by measuring specific inherent optical properties, such as scattering, absorption, beam attenuation and fluorescence. Backscattering and beam attenuation are proxies of suspended particulate material (SPM.), while absorption and fluorescence are CDOM (coloured dissolved organic mater) and chlorophyll indicators. Although latest achievements in optical technology have led to highly sophisticated sensing devices, most existing instruments are used by the scientific community only and can be very expensive [3]. In the project presented here, the main goal was to build a cheap but reliable optical instrument using widely available off-the-shelf components. This instrument will be capable of measuring beam attenuation, backscattering, and fluorescence. The instrument in its final field version, will aim towards groups involved in activities such as coastal engineering and water pollution monitoring in recreation areas and fish-farming. At this stage the beam attenuation (transmittance) mode has been implemented in the laboratory and we present the first results. The attenuation of a beam of light over a known path length can be accurately related to SPM. concentrations as low as 1 mg/L.

2. DESIGN AND IMPLEMENTATION

The configuration for the beam attenuation mode incorporates a Gallium Aluminum Arsenide (GaAlAs) ultra-bright light emitting diode (LED) emitting 3000 mcd at 660 nm (Knightbright L-1513). A 660 nm light source (rapidly absorbed in seawater) ensures that sunlight does not contaminate the received signal, and eliminates attenuation due to CDOM. The emerging 20 deg light cone is focused via an f=+20 mm biconvex to a ~1 mm pinhole for conditioning and a collimated beam with a diameter of 15 mm is shaped with the aid of an f=+50 mm lens. The beam travels through a 130 mm-long attenuation path and then is refocused to a silicon photodiode which

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has an active area of 1.75 mm (IPL-10030) and is fitted with a dichroic red filter to reduce ambient light (Figure 1).

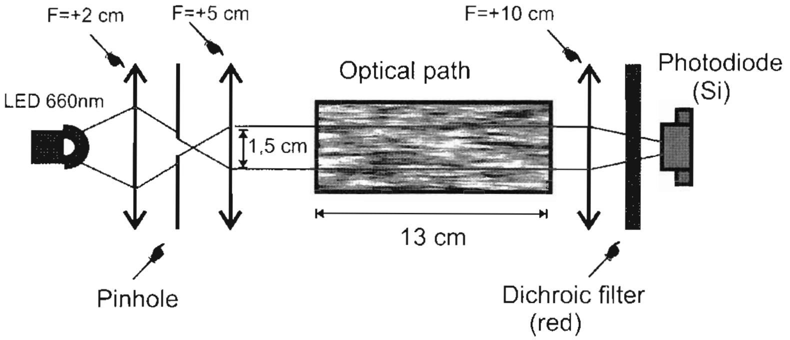

Figure 1. Transmitter and receiver optics.

The LED is driven by a current modulated at 1 KHz to create optical chopping and is electronically maintained to guarantee stability of light intensity (Figure 2, Figure 3). Light intensity can also vary depending on ambient temperature variations. For this reason, there is a provision (not yet implemented) for monitoring the intensity output at the light source and feed it back to the LED driver circuit. The receiving photodiode is reverse biased and wired to an operational amplifier operating in a trans-impedance mode that ensures linear response to light signal. After that, the signal is further amplified by a variable low-gain LinCMOS™ precision and rail-to-rail operational amplifier and is then filtered by a narrow second order band-pass multiple feedback filter. The effect of any changes in ambient light intensity, natural or artificial and any type of high frequency noise is satisfactorily eliminated by this stage of selective gain.

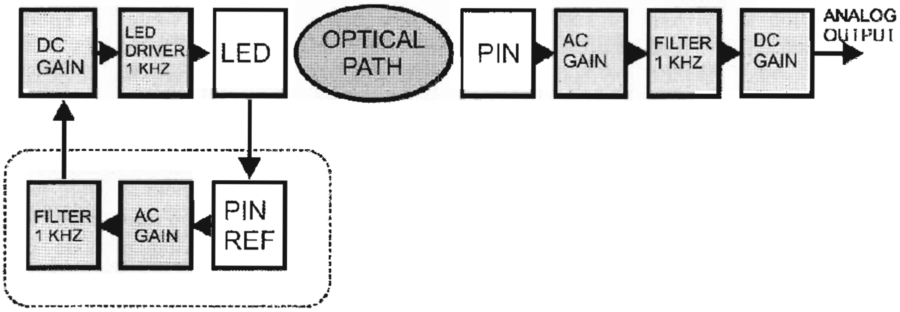

Figure 2. Block diagram of transmissometer's main electronic components.

The output of this signal is then passed through a low-power, precision, true root mean square to direct current (rms-to-dc) converter. The final stage of the analogue circuitry is responsible for the amplification of the dc output in a valid range in order to drive the digital subsystem. The output of the system provides a voltage which is linearly dependent on the intensity of the incident modulated radiation. The digital subsystem is responsible for digitizing the dc output voltage of the analogue subsystem and storing the measurements into a flash memory unit. The Data Acquisition System features a 12-bit successive approximation Analogue-to-Digital Converter (ADC). All the circuitry is powered by a single battery due to the implementation of a virtual ground technique. The laboratory realization of the apparatus, optics and electronics, is depicted in Figure 4.

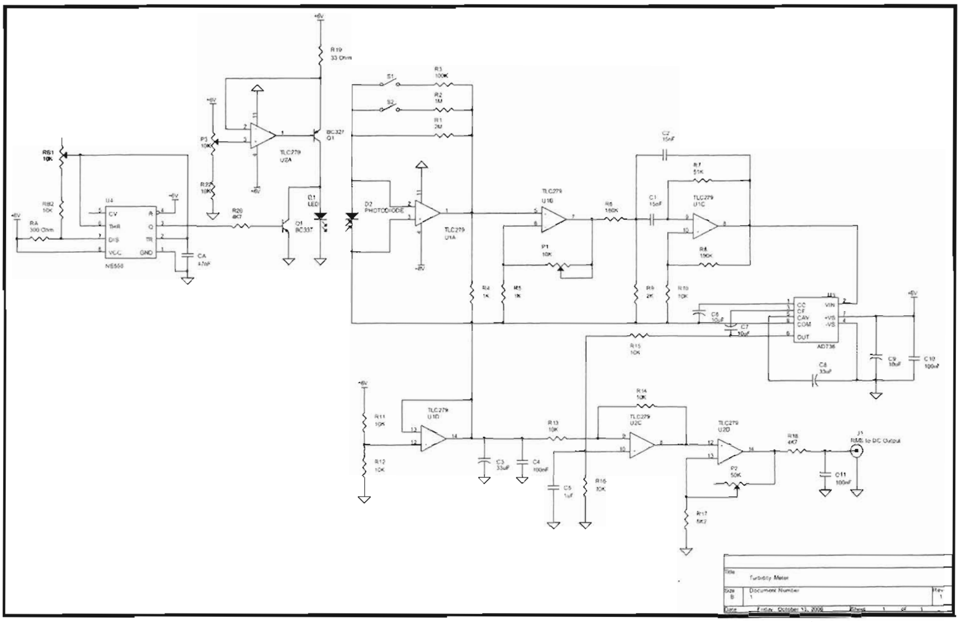

Figure 3. Schematic diagram for the analog and power supply electronics.

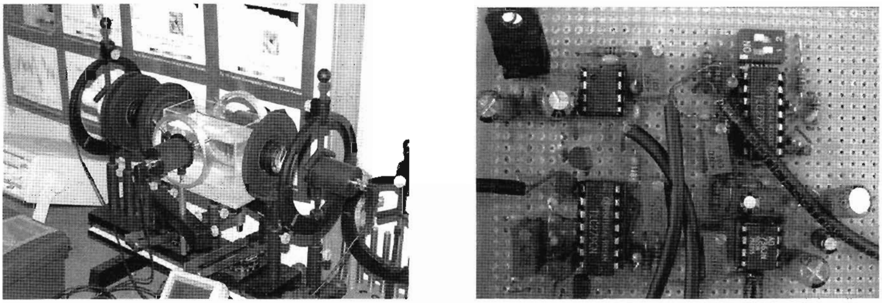

Figure 4. Laboratory version of the apparatus: (a) optics, (b) analog electronics.

3. CALIBRATION AND TESTING

The quantity that a transmissometer measures is the beam attenuation coefficient, which is defined as:

$$bac = -\frac{1}{x}\ln\left(\frac{I}{I_o}\right)$$

Here, x is the optical path length, I and I_0 the beam intensity as is recorded by the photodiode with and without the water sample in place. The beam attenuation coefficient linearly depends on the concentration of the suspended particle material (SPM) present in the water sample and to a less extend on the dissolved mater. For a given concentration, *bac* depends on the size, shape and refractive index of SPM.

The suspended particle concentration in coastal regions of Eastern Mediterranean ranges from ~ 100 mg/L at river mouths to 5-10 mg/L at typical coastal waters. For this reason the calibration and performance testing of the instrument was carried out with suspensions of kaolin (a pure scatterer [4]) in concentrations ranging from 125 mg/L down to 1 mg/L and pure water. The procedure involved the preparation of an initial kaolin suspension at a concentration of 500 mg/L which was successively diluted by adding distilled water to produce several samples. Prior to each measurement, vigorous stirring ensured that the particulate material remained in suspension. Experimental results and a fitted calibration curve are depicted in Figure 5. The zero beam attenuation coefficient corresponds to distilled water (by subtraction of the intercept). The instrument's response to concentrations up to 62 mg/L is notably linear (correlation coefficient 0.997).

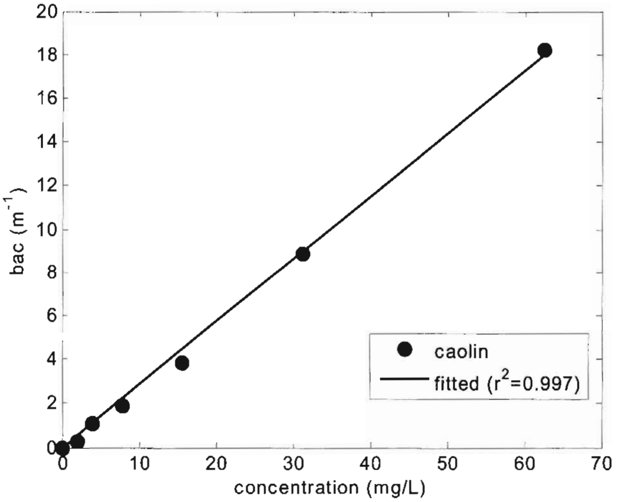

Figure 5. Beam attenuation coefficient (bac) as a function of suspended kaolin concentration.

Cross-calibration with commercially available transmissometers using latex microsphere suspensions is under way. Latex has similar index of refraction with typical minerals present in sea water. Moreover, latex microspheres are available in various diameters and suspensions with size distributions following the Junge cumulative size distribution [5] can easily produced.

4. CONCLUSIONS

The initial laboratory version of the instrument appears to be stable and sensitive enough for typical field measurements. Ongoing tests are currently performed in order to evaluate stability under ambient temperature fluctuations. The value of the materials used does not need to exceed 150 euros. Laboratory experiments for the pure scattering and fluorescence modes are in progress . Chlorophyll, when excited by a source of light in the visible band of the spectrum absorbs light in one region and then re-emits a portion of the energy at longer wavelengths. Thus when excited by blue light re-emits red light. For the fluorescence mode, the same electronics are used; however, the geometry of the optics changes (Figure 6). The sample excitation is achieved by two opposite to each other ultra-bright LEDs (1000 mcd) placed at angle of 40 degrees to the photodiode and emitting a 20 deg light cone at 470 nm. If the blue LEDs are replaced by two red ones (660 nm) then the devices behaves as a scatterometer, another configuration for S.P.M. monitoring.

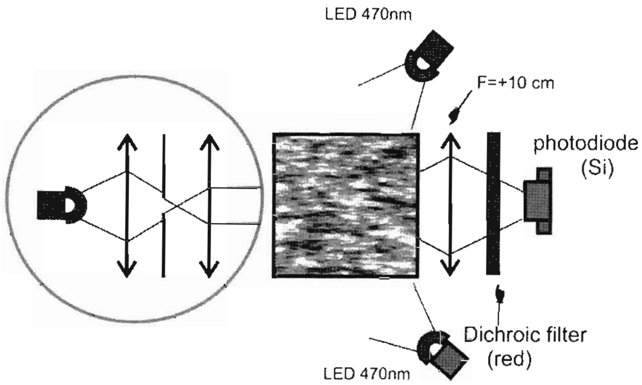

Figure 6. Optical diagram for the fluorometer configuration. During operation, the transmittance mode optics in circle remain de-activated.

In the final field prototype, the device will be enclosed in an Acetal pressure housing having an overall length around 35 cm (Figure 7). In operation, water will enter the probe through entrance ports, pass through the interior sample volume and leave via the exit ports. The electronics are secured in a separate chamber. This configuration is suitable for *in-situ* off-line profiling or monitoring.

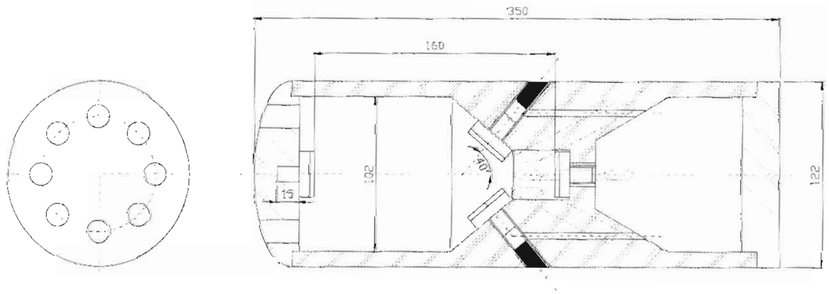

Figure 7. Mechanical diagram for the field version of the instrument.

In conclusion, due to large populations that dwell within the coastal zone, increasing emphasis is being placed upon monitoring of coastal waters. The latter are thus affected by various sources of pollution. Optical sensors are emerging as an important tool for environmental monitoring. Within this context, the present project contributes to the wider availability of such instruments.

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