AN INEXPENSIVE TRANSMITTANCE AND FLUORESCENCE METER

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EXTENDED ABSTRACT

Optical instruments are traditionally used for monitoring the state of coastal waters It is achieved by measuring specific inherent optical properties, such as scattering, absorption, beam attenuation and fluorescence. Backscattering and beam attenuation are re-suspension surrogates, while absorption and fluorescence are CDOM and chlorophyll indicators. Although latest achievements in optical technology have allowed for even more sophisticated sensing devices, most existing instruments target the scientific community and can be very expensive. In this project, the main goal is to build a cheap but reliable optical instrument using widely available off the shelf components. It is targeted to measure beam attenuation, backscattering, and fluorescence. The instrument in its final field version, will aim towards groups involved in activities such as coastal engineering, 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 beam attenuation configuration incorporates a GaAlAs ultra-bright LED emitting at 660 nm where CDOM absorption is negligible. After light is collimated, it travels through an attenuation path 130 mm long and refocused to a silicon photodiode fitted with a red filter to reduce ambient light. The LED is driven by a current modulated at 1 KHz to eliminate stray light through a stage of selective gain. The reverse biased photodiode wired to a trans-impedance mode operational amplifier to ensure linear response. The output of this signal is then further amplified, filtered and passed through a low-power, precision, true rms-to-dc converter.

Calibration and performance testing of the instrument was carried out with suspensions of kaolin 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 which was successively diluted by adding distilled water to produce several samples. The instrument’s response to concentrations up to 62 mg/l was found to be notably linear (correlation coefficient 0.997).

Laboratory experiments are in progress for the pure scattering and fluorescence modes. Again the same electronics are used, however the geometry changes. For chlorophyll fluorescence measurements, the sample excitation is achieved by two opposite facing ultra-bright LEDs emitting at 470 nm and fitted at an angle of 40 degrees to the photodiode. In the final field prototype, the device will be enclosed in a black acetal housing having an overall length not exceeding 35 cm.

Keywords: ocean optics, optical instruments, environmental monitoring

1. INTRODUCTION

The use of optical instruments for monitoring the state of coastal waters is a common practice during the last decade [1],[2]. It is achieved by measuring some optical properties, such as scattering, absorption, beam attenuation and fluorescence. Scattering and beam attenuation are proxies of suspended particulate mater (S.P.M.), while absorption and fluorescence are CDOM (coloured dissolved organic mater) and chlorophyll indicators. Latest achievements in optical and electronics technology have led to highly sophisticated sensing devices, however, most existing instruments aim towards the scientific community and can be very expensive [3]. In the project reported here, the main goal is to build a cheap and reliable optical instrument using widely available off the shelf components. It will be capable of measuring beam attenuation, backscattering, and fluorescence. In its final field version, the instrument will target groups involved in activities such as coastal engineering, 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 S.P.M. concentrations as low as 1 mg/l.

2. LABORATORY IMPLEMENTATION

The configuration for the beam attenuation mode incorporates a GaAlAs ultra-bright LED emitting 3000 mcd at 660 nm (Knightbright L-1513). A 660 nm light source (rapidly absorbed in sea water) 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 has an active area of 1.75 mm (IPL-10030) and is fitted with a dichroic red filter (Edmund Optics NT52-527) to reduce ambient light. The transmitter and receiver optics are depicted in Figure 1.

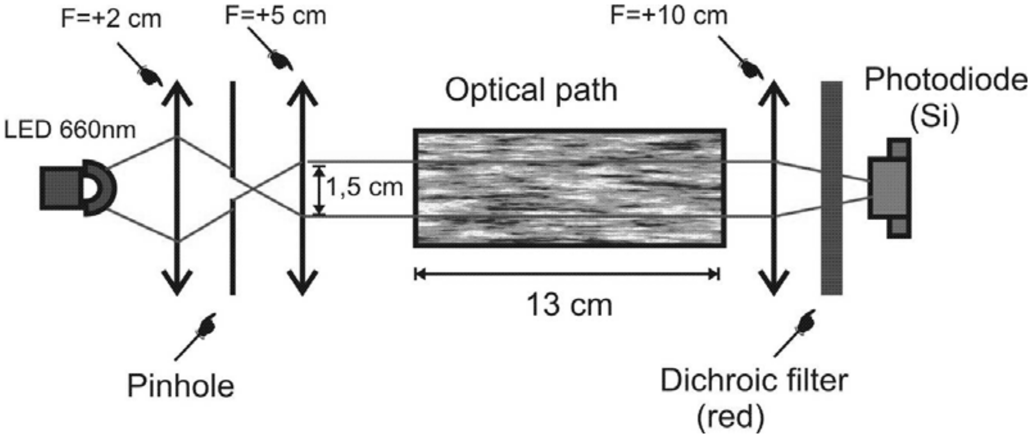

Figure 1: Transmitter and receiver optics.

The LED is driven by a current modulated at 1 KHz to generate 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 changes. 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 intensity. 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.

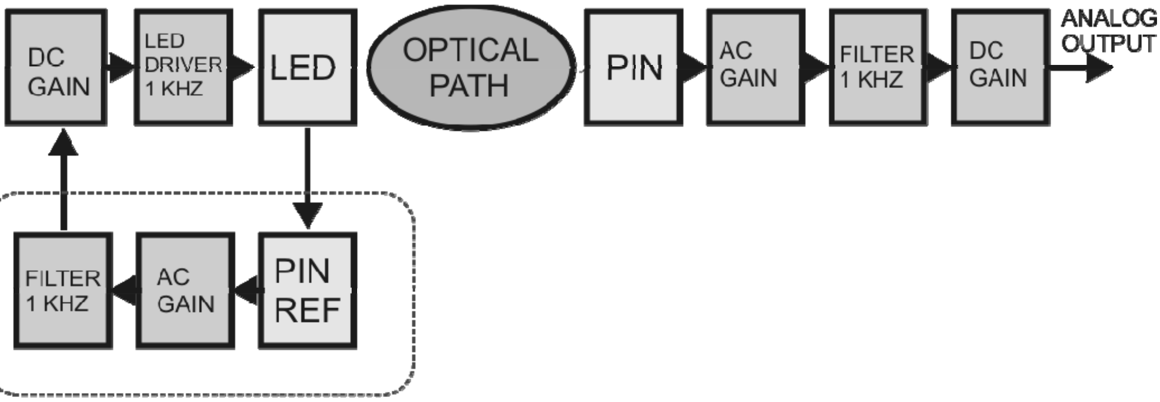

Figure 2: Block diagram of transmissometer's main electronic components

The output of this signal is then passed through a low-power, precision, true rms-to-dc converter which maintains high accuracy, while computing the true rms measurements. It consists of five subsections which are the input amplifier, full-wave rectifier, rms core, output amplifier and bias selection. 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.

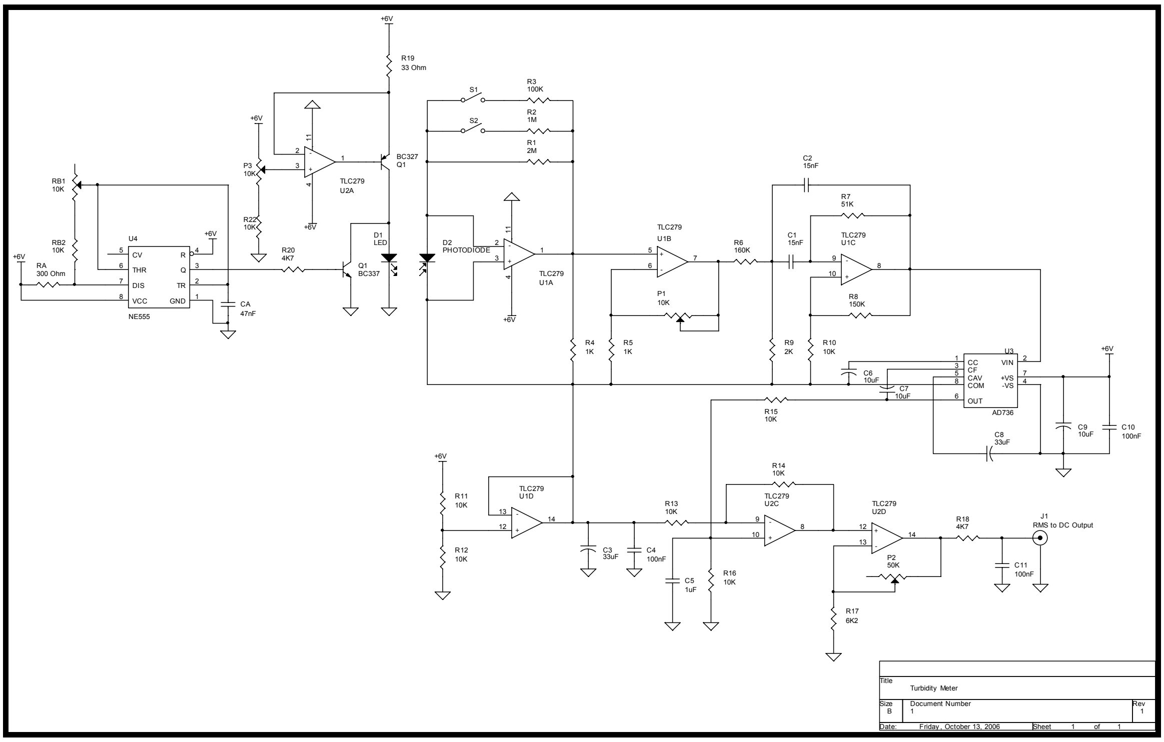

Figure 3: Schematic diagram for the analog and power supply electronics.

A common problem in analog electronics is a requirement for a dual-voltage supply (e.g. +/-5V) but only having a single supply available, such as battery. The innovation in this electronic design is the use of single power supply for all the circuitry by using a virtual ground technique. The proposed circuit provides a way to “split” this single supply so that it behaves like a dual power supply. The digital subsystem is responsible for digitizing the dc output voltage of the analog subsystem and storing the measurements into a flash memory unit.

The laboratory realization of the apparatus, both optics and electronics, is presented in Figure 4.

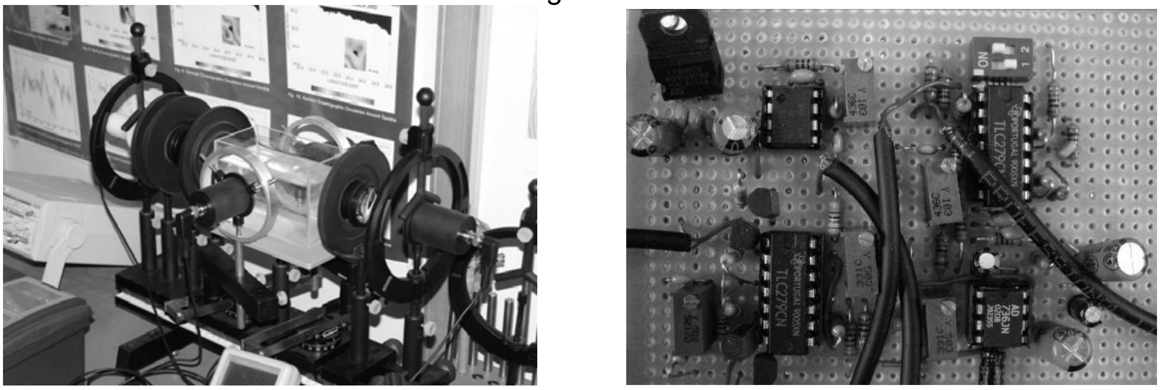

Figure 4: Laboratory version of the apparatus: (a) optics, (b) analog electronics.

3. PERFORMANCE TESTING

The inherent optical property that the transmissometer monitors is the beam attenuation coefficient. It 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 depends linearly on the concentration of the suspended particle material (SPM) present in the water sample. To a less extend depends on the dissolved mater (i.e. CDOM). Since the wavelength of operation of the present device was chosen to be in the red part of the visible spectrum this absorption signal is negligible. Moreover, for a given concentration, *bac* depends on the size, shape and refractive index of SPM. Therefore water samples with same concentrations can easily have completely different attenuation coefficients.

The suspended particle concentration in coastal regions of Eastern Mediterranean ranges from ~ 100 mg/l near 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).

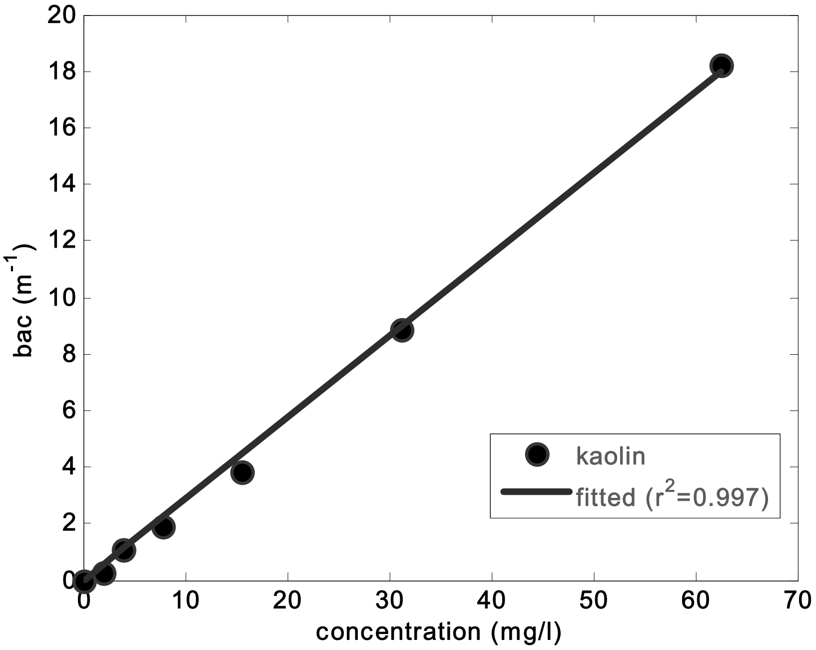

Figure 5: Beam attenuation coefficient as a function of suspended kaolin concentration.

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. DISCUSSION

The initial laboratory version of the instrument appears to be stable and sensitive enough for typical field measurements. Furthermore, there are ongoing tests in order to evaluate stability under ambient temperature fluctuations. Laboratory experiments are in progress for two more modes of operation: the fluorescence and pure scattering. Fluorometers use the principle of fluorescence to estimate the amount of chlorophyll in a volume of water. Chlorophyll-α which is present in algae, when excited by a source of light absorbs light in one region of the visible spectrum 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. The red filter in front of the photodiode stops blue scattered and modulated light of reaching the sensitive surface and only red fluorescent light is monitored. The blue LEDs can be replaced by two red ones (emitting at 660 nm), in order for the device to become a scatterometer, another configuration for S.P.M. monitoring. What is measured now is the radiation which is back-scattered from the suspended material and is proportional to its concentration. This particular configuration is more appropriate for environments where dense suspensions exist (e.g. river mouths, [3]) and transmissometers fail to operate reliable.

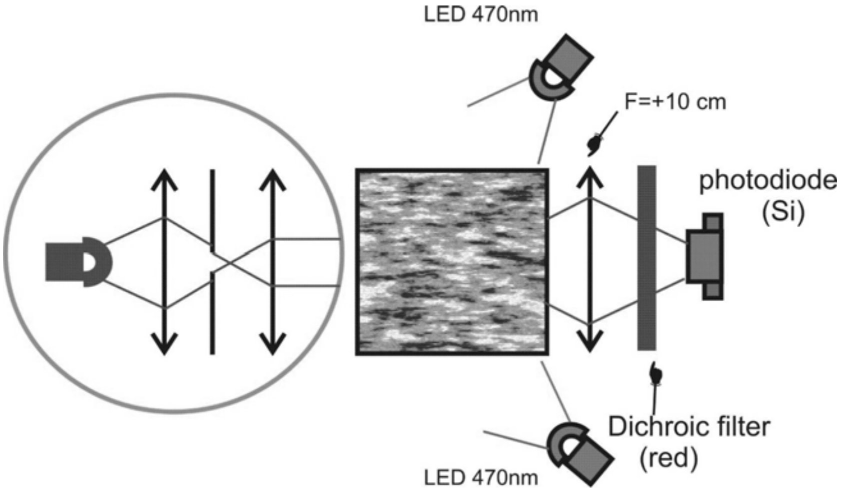

Figure 6: Optical diagram for the fluorometer configuration. During operation, the transmittance mode optics in circle remain de-activated.

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 [6]. The electronics are secured in a separate chamber. This configuration is suitable for in-situ off-line profiling or monitoring. The value of the materials used does not need to exceed 200 euros.

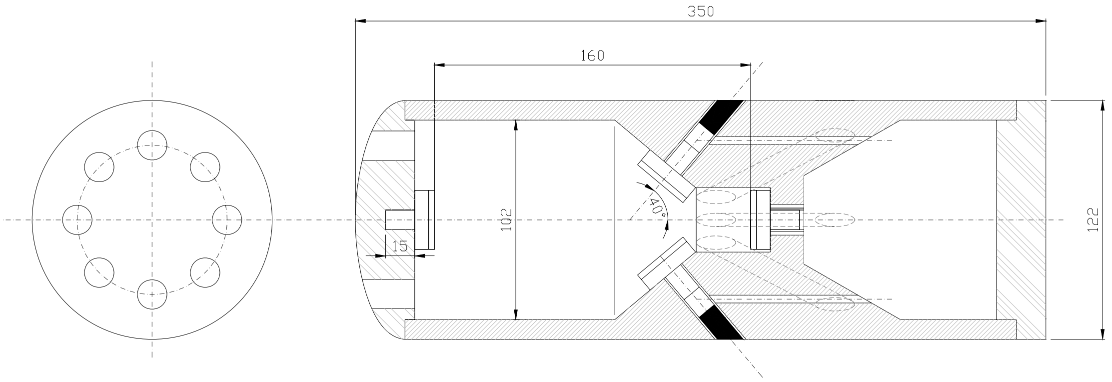

Figure 7: Mechanical diagram for the field version of the instrument.

In conclusion, due to the large population that dwells within the coastal zone, increasing emphasis is being placed upon monitoring the quality of coastal waters. They are affected by various sources of pollution and optical sensors are emerging as an important tool for environmental monitoring. Within this context, the present project will contribute to a wider availability of such instruments due the targeted low cost of production.

ACKNOWLEDGEMENTS

This work is co-funded 75% by the E.U. and 25% by the Greek Government under the framework of the Education and Initial Vocational Training Program- Archimedes

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