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MODELLING A BUOY FOR SEA POLLUTION MONITORING USING FIBER OPTICS SENSORS

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Abstract: This paper describes a prototype of a new buoy equipment for monitoring sea pollution that utilizes fluorescence chromatography of known biomass to determine which of them are present and in what capacity.The hardware system of the buoy is mainly composed of optical sensors for monitoring, circuitry on the measurement chain, the remote control system on GSM channel, and rechargeable battery with photovoltaic system.The software used in order to obtain a high resolution spectral analysis processing data is based on the Decimated Padé Approximant and Decimated Linear Predictor. Design is the results of simulations with COMSOL software.

Keywords: Water Pollutants, Fiber Optics Sensors, Oceans Spectrometer, RTU-GSM, Energy Harvesting, DPA, DLP.

1. INTRODUCTION

The European Directive 2008/56/EC[1] establishes a program of Community action in the field of marine environmental policy. The Article 11 externalizes the necessity of implementing a monitoring program, coordinated with each Member State, for the ongoing assessment of the environmental status of marine waters, making efforts to set targets that define good environmental status of the marine component. Each target is marked as achieved if the variables under observation are the values that fall within the range defined by the legislature. But what happens if the legislature 'forget' a variable? A goal achieved implies a marine environment still to be considered in good condition? For example, the European Decision 2001/2455/EC [2] establishing a list of priority substances in the field of water policy. It is questionable whether this list is exhaustive or may continue to be so in the future. The need for ongoing research and continuous analysis of possible causes of pollution requires the effort of many experts in the field and funds that often are insufficient for a thorough investigation, rather than precise. Ignoring even only one variable in the construction of a mathematical model can be a problem that makes it not applicable, even if true, the model itself. Being able to solve the problem of the gap between theory and reality is therefore a fundamental objective that cannot be ignored. The list of priority substances present in the Decision2455/2001/EC is, therefore, considered as potentially incomplete.

Recently, the European Decision 2010/477/EU has established criteria and methodological standards on good environmental status of marine waters. In particular, the Descriptor 8 (Concentrations of contaminants are at levels not giving rise to pollution effects) states that "the concentration of contaminants in the marine environment and their effects need to be assessed taking into account the impacts and threats to the ecosystem"[3].

With this work we would like to implement a system capable to fulfil this task but that is able to detect unexpected situations such as the appearance of a new pollutant. To obtain this result we are creating a system for monitoring broad spectrum based on chromatography of the fluorescence of known biomass in the bi-spectrum, through a double frequency mapping. That can have a complete picture of the spectrum emitted by all the elements contained in the water, even if some items are not known to the examiner. For example, chlorophyll*a* emits fluorescence in the wavelength of 680-760*nm* which can be detected and measured using opto-electronic equipment that separate the fluorescence from the light emitted [4]. Other substances that can be detected are presented inTable1.

Substance	λ_{ex} (*nm*)	λ_{em} (*nm*)
Chlorophyll*a*	680	760
Benzene	270	310
Methylbenzene	270	320
Chlorobenzene	275	345
Hydroxybenzene	285	265
Aniline	310	405

Tab. 1 Example of substances with known fluorescence.

2. MARINE BUOY ASPECTS

Community interests in the ecologic quality of water have originated in 1988, following a community water policy seminar held in Frankfurt, in which it was determined that there was a lack of laws that regulated community actions concerning water. This lack was formalized the same year with a Council Resolution published in the Official Journal of the European Union[5]. The Council asked the Commission to create proposals that could regulate and protect the ecologic quality of the European waters. On this path, in 2000 the Directive 60 established the first Community Framework which regulates and coordinates community actions [6].

Since then, many research institutions have combined their efforts in the implementation of tools and procedures designed to monitor water. In particular, pollution, because of its impact on public opinion, has been the subject of many topics and questions addressed not only by the scientific community, but also the political one. Necessity has created instruments that are at the cutting edge of innovation, with the purpose to know and study water status in real time. In the marine field, we have the creation of buoy used for the monitoring of coastal areas, and useful in the measuring of parameters such as: temperature, salinity, current, wind, chlorophyll, oxygen, depth, etc.

Different types of buoys exist today; for example those that transmit a very large amount of geo-referenced data, and can be deployed either in the open sea for periodic measurements of offshore pollution. In marine research, buoys, capable of tracking any of the parameters (density, salinity, temperature, closed depth) calculated by measurements performed by its own sensor system, are used. For example, the buoy can be kept in an area where the temperature is constant. A two-way communications system enables the buoy to transmit data and to receive instructions from a base on land or at sea.

In 1990s, the research focused to providing quality products to specific global niche markets (environmental monitoring and testing, precision temperature measurement, and biotechnology) while continuing to reduce costs. The buoys can be used for oil spill surveillance constitutes an important component of oil spill disaster management. Advances in remote sensing technologies can help to identify parties potentially responsible for pollution and to identify minor spills before they cause widespread damage. Due to the large number of sensors currently available for oil spill surveillance, there is a need for a comprehensive overview and comparison of existing sensors. Laser fluorosensors were found to be the best available sensor for oil spill detection since they not only detect and classify oil on all surfaces but also operate in either the day or night .

3. MODELLING AND DESIGN PROPOSAL

The buoy project system consists of 3 steps:

- Design
- Hardware
- Software

The design of the buoy has been thought primarily to meet the basic criteria such as: buoyancy of the whole system, housing the various electronic control devices end housing the sensors used.

The figures below show the main components which form the full system.

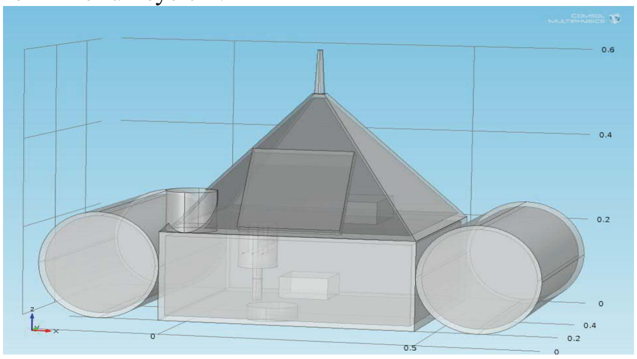


Fig. 1 Buoy system, front full

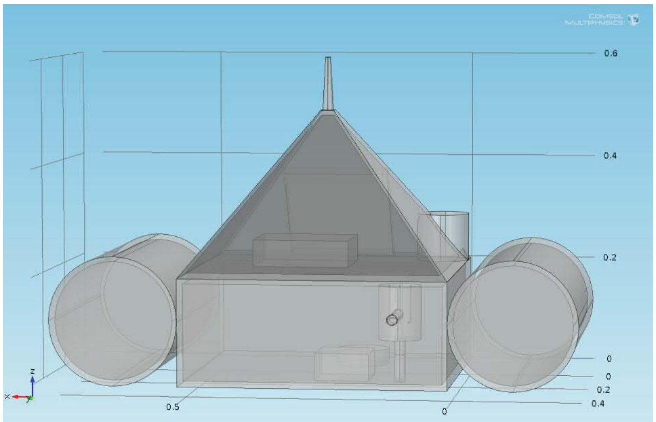


Fig. 2 Buoy system, back full

The system hardware includes:

- sensors related to environmental monitoring;
- control circuits for proper operation of the sensors;
- circuitry on the measurement chain and the remote control system on channel GSM (GSM-RTU: Remote Terminal Unit)[7];
- rechargeable battery with photovoltaic system.

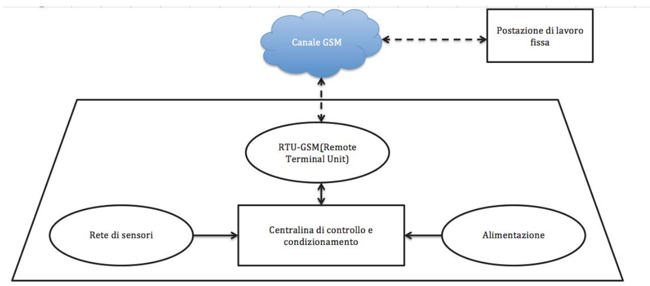
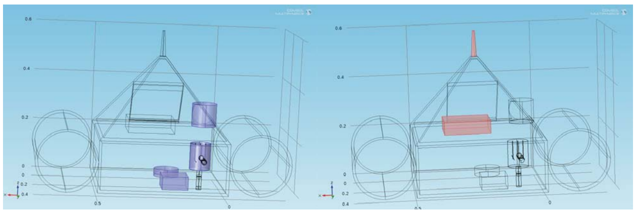


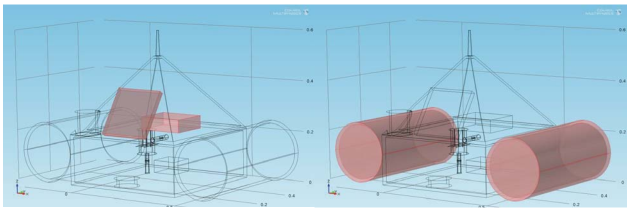
Fig. 3 Flowchart hardware system

The sensory system is structured by a network of sensors located inside a chamber, in order to isolate the sample from interference caused by ambient light.

They are fitted with optical fibers for the transport of light from the lamps (which emit signals in the UV, IR and RGB) up to the ball and the ball to the spectrometer [8].



(a) (b)
Fig. 4(a) Housing sensors employed; (b) Housing RTU-GSM.



(a) (b)
Fig. 5(a) Housing photovoltaic system; (b) Housing floats.

The experimental setup uses an integrating sphere in which the water sample to be analyzed is housed, contained in a vial (cylinder) of glass. Inside the integrating sphere two optical fibers are connected, respectively, from a source and a spectrometer. In practice, all the light that enters the integrating sphere is diffused from the walls of the sphere, and the fiber connected to the detector collects the totality of the diffused light. When inside the sphere an absorbing medium is inserted, such as a water sample, the radiance of the sphere decreases at different frequencies which correspond to the polluting components in which they interact [9].

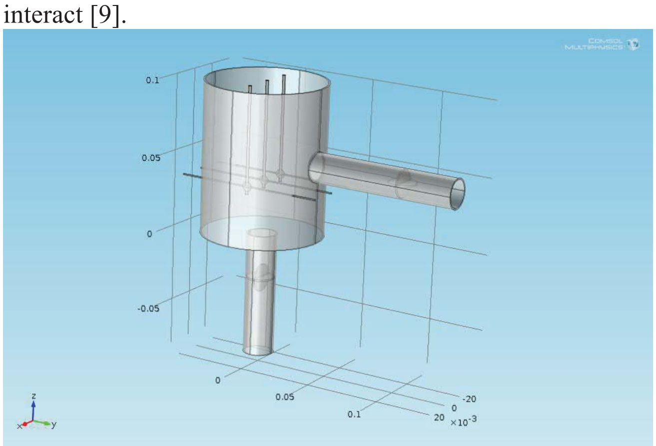


Fig. 6 Chamber for sensors.

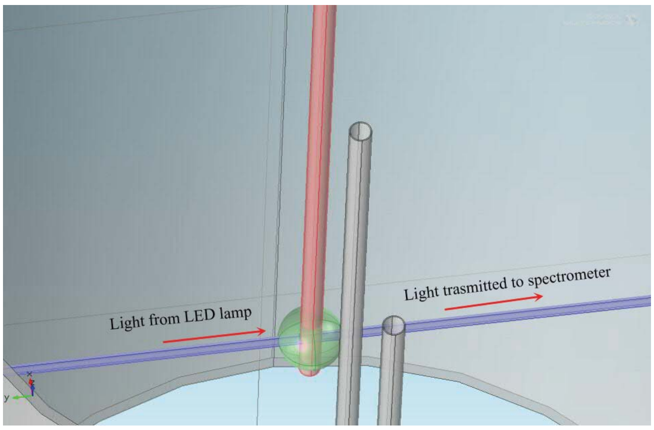


Fig. 7 Principle of optical fiber for the transport of light.

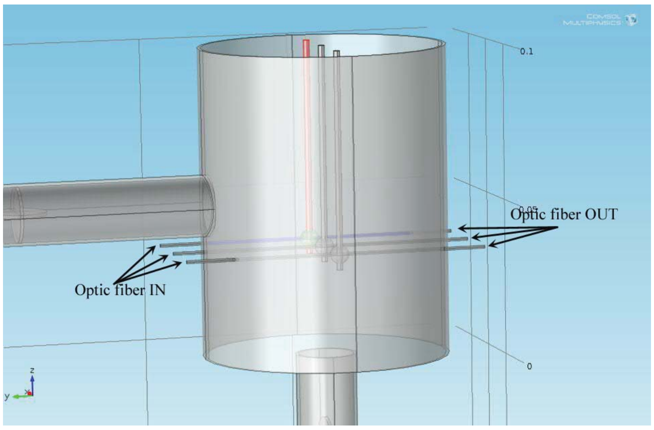


Fig. 8 Connections optical fiber with LED lamps input and with spectrometer output

The expression that relates the power of light revealed the characteristics of the elements is described by the equation:

$$P = \frac{R*P_0*A_d}{S} * \frac{1}{1-\frac{R}{S}*(S-A_S-\alpha*V)} \quad (1)$$

where: P_0: source power at the entrance of the sphere with water sample without contaminants; P: power revealed in presence of contaminants, α: absorption coefficient of the sample measured; V: volume of the sample; A_d: Area of the fiber revelation; A_s: area of the fiber lighting; R : reflectivity of the integrating sphere; S: area of the inner surface of the integrating sphere.
As the initial step is measured as the term of comparison the P_0, that is, by measuring a sample of water free of contaminants to then compare it with the samples taken subsequently P

$$A = -log_{10}\frac{P}{P_0} \quad (2)$$

The project plans to equip the buoy with a remote control system on GSM channel called RTU-GSM, with it one can send the data from the sensor to a base station for processing with advanced algorithms (in order to obtain spectral analysis with more high resolution) and to receive signals for the control of the devices themselves.
The software used for data processing is based on advanced algorithms such as DPA (Decimated Padé Approximant) and DLP (Decimated Linear Predictor) [10] [11] [12]. These algorithms allow us to obtain high-resolution spectral analysis processing data in matrix form and limited bands (or decimated), that have been previously used for analysis of EEG and ECG signals and for detecting leaks in water pipes.
As an alternative method for solving the nonlinear system

$$c_n = \sum_{k=1}^{K} d_k z_k^n \quad (3)$$

we now propose to apply the method of DPA. This is the standard Padè approximant (PA) but applied to our band-limited decimated signal c_n. Let us assume for the moment that the signal points c_n are known up to infinity, $n = 0,1,\ldots,\infty$. Interpreting the c_n as the coefficients of a

Maclaurin series in the variable z^{-1}, we can then define the function

$$g(z) = \sum_{n=0}^{\infty} c_n z^{-n} \quad (4)$$

With equation (1) and the sum rule for geometric series we obtain

$$g(z) = \sum_{n=0}^{\infty} c_n z^{-n} = \sum_{k=1}^{K} d_k \sum_{n=0}^{\infty} \left(\frac{z_k}{z}\right)^n = \sum_{k=1}^{K} \frac{z * d_k}{z - z_k} \quad (5)$$

$$\equiv \frac{P_K(z)}{Q_K(z)} \quad (6)$$

The right-hand side of equation (3) is a rational function with polynomials of degree K in the numerator and denominator. Evidently, the parameters $z_k = exp(-i\omega'_k \tau)$ are the poles of $g(z)$, i.e., the zeros of the polynomial $Q_K(z)$. The parameters d_k are calculated via the residues of the last two terms of (6). We obtain

$$d_k = \frac{P_K(z_K)}{z_k P'_K(z_K)} \quad (7)$$

with the prime indicating the derivative d/dz. Of course, the assumption that the coefficients c_n are known up to infinity is not fulfilled and, therefore, the sum on the left-hand side of equation (6) cannot be evaluated in practice. However, the convergence of the sum can be accelerated by application of DPA. Indeed, with DPA, knowledge of $2K$ signal points $c_0, \ldots, c_{2K-1}$ is sufficient for the calculation of the coefficients of the two polynomials

$$P_K(z) = \sum_{k=1}^{K} b_k z^k \quad (8)$$

$$Q_K(z) = \sum_{k=1}^{K} a_k z^k - 1 \quad (9)$$

The coefficients a_k, $k = 1, \ldots, K$ are obtained as solutions of the linear set of equations

$$C_n = \sum_{k=1}^{K} a_k c_{n+k} \quad (10)$$

which is identical to equations (3) and (4) for DLP. Once a coefficients are known, the coefficients b_k are given by the explicit formula

$$b_k = \sum_{m=0}^{K-k} a_{k+m} \, c_m \quad (11)$$

It should be noted that the different derivations of DLP and DPA provide the same polynomial whose zeros are the z_k parameters, i.e., the z_k calculated with both methods exactly agree. However, DLP and DPA do differ in the way the amplitudes, d_k, are calculated. It is also important to note that DPA is applied here as a method for signal processing, where the Padè approximant is used for the direct summation of the periodic orbit terms in Gutzwiller's trace formula [13].

4. CONCLUSION

The BOA project has been realized as modeling, from a structural base designed in COMSOL and applying hardware and software systems that have already been already the subject topic of previous research carried out in different areas [14] [15] [16].
The proposed sensors have been redesigned to better adapt to this type of project and to overcome physical limitations due to several known structural problems specific to the marine environment where they operate.
As for the sensors also software (algorithms cited) has been adapted to the morphology of the outgoing signal from this type of sensors, as they have been developed for various fields such as the analysis EEG, ECG and for the detection of leaks in water pipes.

It aims at to create a prototype of this system in all its parts in order to reconcile the theoretical study (ideal) and the reality of the physical limits of performance of all components and check for compatibility between them. The proposed system could be included in a network of sensors for environmental issues [17] and a marine video surveillance can be used for further verification of buoy status [18].

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