

# *A multi-wavelength discriminating sensor with a wireless mote interface for aquatic pollution monitoring*

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**Abstract**—The system presented in this paper demonstrates how a novel fibre optic based sensing platform, capable of detecting minute changes in the level of impurity in a liquid, can be incorporated onto a Mote based platform enabling real time monitoring of a body of water. How these features can be used to detect a representative sample of chlorophyll within a aquatic environment, will be demonstrated. Systems currently deployed worldwide include satellite mapping technology and high cost water monitoring platforms. Growing international emphasis on the management of water quality is giving rise to an expansion of the international market for novel robust, miniaturized, intelligent water monitoring systems capable of measuring local environmentally detrimental events such as localised small scale chemical pollution.

**Index Terms**:—Mote, SHIMMER, Chlorophyll, Sensor, WSN Platform, Aquatic Sensing, Pollution.

## I. INTRODUCTION

Aquatic environments are influenced by a wide variety of man-made and natural substances. Real-time measurements of pollutants across a range of scales are required to adequately monitor for such hazards to manage the consequences and to understand the processes governing their scale and distribution. [1] The system presented in this paper, demonstrates a novel fibre optic based sensor, capable of detecting minute changes by absorption losses within a liquid. The sensing element has been interfaced to a mote based platform. The system presented also demonstrates flexibility for the detection of many other substances that are defined as pollutants and flexibility in measuring quality indicators in the aquatic environment such as Chlorophyll a and b.

## II. EU LEGISLATION

The European Union Water Framework Directive (Directive 2000/60/EC) [2] has created a demand among government monitoring agencies and legislative bodies throughout Europe for water quality monitoring systems that are able to monitor reliably, a larger number of water quality parameters at regular intervals. This requires trained personnel, reliable instrumentation and in the long run, high laboratory costs to achieve the expected monitoring goals. The Marine Strategy

Framework Directive (MSFD) (Directive 2008/56/EC) [3] is also notable for its provisions dealing with environmental protection requirements in marine waters, for example setting the requirement for EU Member States to achieve “good environmental status” in their marine waters by 2020. This is expected to be accomplished through careful monitoring of surface water and groundwater habitats across Europe and the implementation of gradual improvements towards the ultimate goal of attaining a ‘good maritime ecological status’.

## III. SENSING IN AN AQUATIC ENVIRONMENT

When a pollutant enters the aquatic environment there is very often considerable time lag before the negative impact on the environment is detected. The subsequent development and implementation of policies, the deployment of counter-measures and, eventually, the visible manifestation of a positive impact based on the response also lead to delays. Water quality has traditionally been monitored by conventional measurements (e.g. Secchi disk, PH and EC meters) [4]. Although these kinds of measurements provide relatively accurate data, they require human based in situ sampling, as well as expensive and time-consuming laboratory work. Nowadays remote sensing offers the possibility of covering a large spatial area with a high temporal frequency. It also provides monitoring of the spatial distribution, which is difficult to carry out by direct sampling. The remote sensing being outlined utilises optical fibres which offer many advantages for monitoring, such as their immunity to electrical and electromagnetic interferences, and indeed the ability to remotely monitor in real-time. Pollutants are a common and sometimes natural occurrence in the environment. The monitoring and detection of pollution as it occurs in real-time accelerates response time - thus substantially reducing clean-up and remediation costs as well as limiting damage to the environment.

## IV. SENSING PRINCIPLE

Spectroscopy is the study of how a sample/substance responds to light. When a beam of light passes through a substance or a solution, some of the light may be absorbed with the remainder transmitted through the sample. The sensor presented is based on an interaction of the optical field of light-guiding fibres and the substance to be detected. The fibres consist of a plastic optical fibre and a polymer cladding. If the substance under test is a solution with impurities to be detected, then the principle is that the substance being tested for presence in the solution is a known sample that has been classified using spectroscopy. Prior to developing the sensor the classification of the polluting substance had been

analysed, and the peak wavelengths that are used to classify the substance were identified, then by capitalising on the absorption properties as outlined below it is possible to identify the presence of the pollutant in an aquatic environment using the intensity of the signal when propagated through the polluting substance which is best represented in terms of Absorbance, A: [5-7]

$$(1) A = \ln(I_0/I) = \sigma CL$$

Where,

- $I_0$ : Incident intensity
- $I$ : Transmitted intensity
- $\sigma$ : Absorption cross section
- C: concentration of molecules
- L: Path length - the distance that the light travels

This absorption principle can be summarized by aligning two plastic optical fibres with a source wavelength passing through a substance of interest with the same peak of transmission, this allows for the substance to allow the passing through of the wavelength transmitted. The diagram below outlines passing multiple wavelengths through the same substance of interest and all other wavelengths of light getting absorbed and only the wavelength that corresponds to the substance present being able to pass through to the detecting fibre.

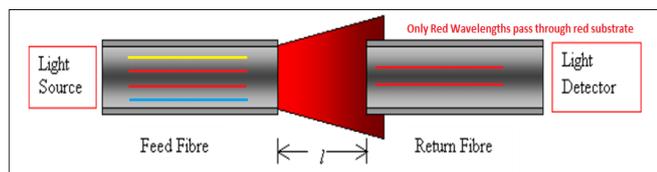


Figure 1: Wavelength Absorption through substance of interest

In order to create the sensor it was essential to first align three fibre pairs in a transmitter/receiver configuration and to have them anchored in a configuration that allowed for the detection of the wavelength of interest by having a wavelength just below the wavelength of interest and just above the wavelength of interest on the spectrum. This enabled the detection of the wavelength of interest by means of logic circuitry connected to the detectors on the receiver fibres. The aligning of the sensors was achieved by bonding the plastic optical fibres to a block of PolyTetraFluoroEthylene (PTFE). [8] PTFE was chosen as it has high reflection properties across the visible spectrum and is also resistant to corrosion in water. The PTFE countered any significant light spreading that occurs at the opening of fibres. This led to the sensor head design as presented in figure 2. It has for demonstration purposes three different colours/wavelengths in order to show the three paths that were routed through the PTFE block for the housing of the POF fibres.

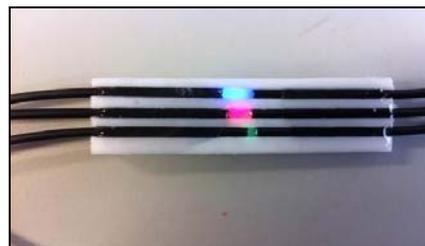


Figure 2: Optimal Sensor head design.

## V. EXPERIMENTATION

In Figure 3 a spectrum of the absorption of visible light of both Chlorophyll a and b is shown. The spectrum clearly shows the peak wavelengths of interest when ascertaining the presence of chlorophyll a or b.[9, 10]

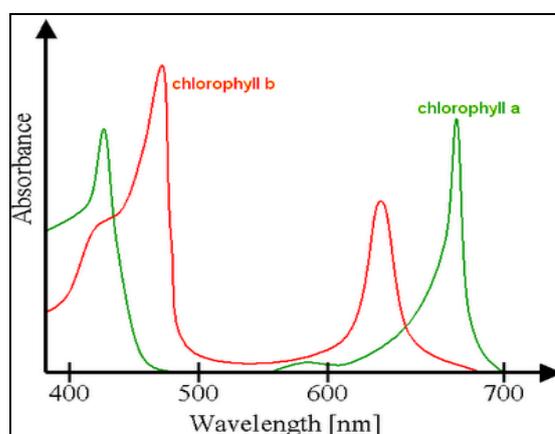


Figure 3: Visible light absorption of Chlorophyll a and b

Utilising the spectrum to identify the presence of Chlorophyll-a or Chlorophyll-b a method for detecting the wavelengths that correspond to the peaks can be manufactured by using LED light sources and light detector circuitry for the in-situ testing. From the absorption spectra it was noted that Chlorophyll a has a peak at 430nm and at 660nm while Chlorophyll b has a peak at 480nm and 630nm. A sample of chlorophyll was obtained from spinach for testing. When the peak wavelengths of interest are illuminated, it is possible using the absorption properties of the liquid to determine the presence of chlorophyll. For the detection process a representative selection of light emitting diodes (LED's) with a narrow beam centre wavelength of 370nm, 390nm, 430nm, 465nm, 525nm 626nm, 660nm and 700nm were used. A sample of extracted chlorophyll was utilised to test the POF sensor head. Spinach was chosen as it is a good source of both chlorophyll-a and chlorophyll-b [11]. The chlorophyll was extracted using the technique of washing the spinach and then placing some cut leaves in a mortar [12]. Acetone was then added to the cut leaves in a ratio of 2:3 i.e. 2 grams of cut spinach leaves to 3ml of Acetone. Chlorophyll is soluble in acetone and after adding acetone to the spinach it results in the extraction of the chlorophyll from the spinach. The leaves were then ground down with a pestle. The green liquid run-off was then decanted into a screw cap bottle. 3ml more Acetone was added to the leaf residue that remained in the mortar, to

which 5ml of hexane was also added. Again the pestle was used to grind the leaves and the run-off was filtered into the same screw top bottle. The bottle was then shaken vigorously. The substance then had brine added to facilitate the separation process and finally filtered to remove the remaining residue. This process resulted in a sample of chlorophyll for testing as shown in figure 4.



Figure 4: Chlorophyll Extracted From Spinach

The wavelengths were then passed through the sample of chlorophyll obtained. Accordingly, the LED's emitted wavelengths were either absorbed or transmitted allowing a chart to be drawn outlining the corresponding results. It shows the conditions for detecting chlorophyll were met and that the sample proved to have chlorophyll present in the liquid, as outlined in Figure 5.

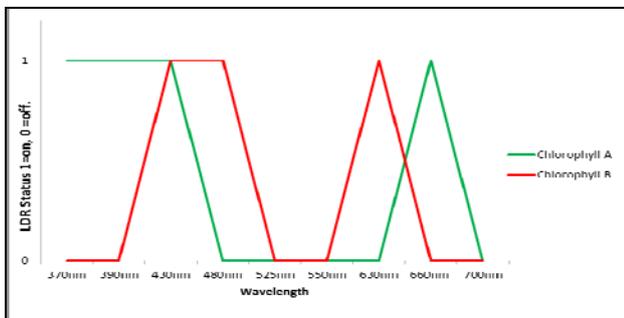


Figure 5: Chlorophyll and LDR Status at Wavelengths

What has been demonstrated is a method of determining the presence of spectral conditions in a liquid and as such it is therefore possible to measure for multiple substances that may be present in a liquid once the spectrum of said substance is known beforehand and a prescribed condition can be met. With this principle in mind, it shows that the system can be adjusted and applied to many other spectra for detection. Thus demonstrating that the system can be calibrated to measure for multiple substances.

#### VI. THE SHIMMER PLATFORM

SHIMMER is a small wireless sensor platform designed to support wearable applications. It provides an extremely

extensive platform for real-time kinematics and physiological sensing. It features low-power standards based wireless communication technologies and a large storage capacity which facilitates wearable wireless sensing in both connected and disconnected modes. The initial Wireless sensor network incorporated two prototype sensors that were interfaced to the SHIMMER via interface circuitry. This allowed for the SHIMMERS to relay real-time results wirelessly from the fibre optic circuits back to the base station nearby. Shimmer which stands for Sensing Health with Intelligence, Modularity, Mobility, and Experimental Reusability incorporates a technology licensed from Intel Corp. An example of the SHIMMER is shown in figure 6.

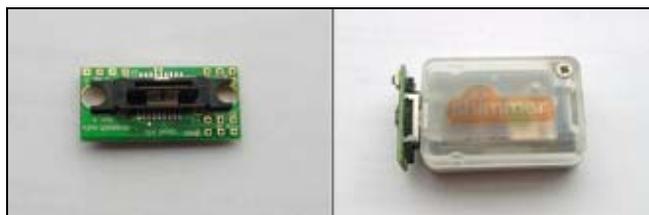


Figure 6: SHIMMER Wireless Sensor with Annex Interface board

The platform features a 2GB removable storage capacity and low-power, standards-based wireless communication technologies that enable standalone applications such as robust motion capture. Shimmer can also stream data to other devices to expand the scope of research applications. In this case, the shimmer platform was used in a method that it wasn't originally designed for; here it interfaces with the fibre sensors through the annex board that is supplied with it.

#### VII. THE SHIMMER INTERFACING

The interfacing to the SHIMMER mote was achieved through the Annex daughterboard or Analog Expansion board but the fibre optic signals also needed to be conditioned to the correct voltage levels, and as such an interface circuit for the Annex board was required. Since the prototype sensor platform was designed to be able to discern between three wavelengths it became necessary to implement a logic circuit that would trigger the SHIMMER mote via the annex interface board. A prototype version of the sensor interfacing board that was interfaced to the SHIMMER is shown in figure 7.

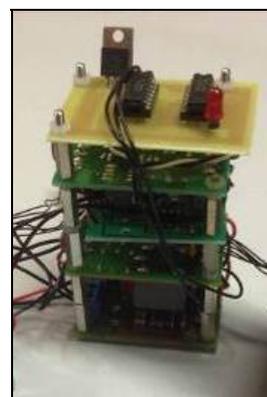


Figure 7: Finalised Interface Circuits

The SHIMMER was configured to be triggered when the correct combinations of wavelengths were present at the sensor head, which indicated the presence of a peak wavelength. Therefore, a truth table to create the relevant logic circuitry for the discrimination of the wavelengths was required. The truth table was in turn used to develop a schematic of the logic circuitry, which was manufactured using transistor-transistor-logic (TTL) integrated circuits. It was decided to use inverters/NOR gates (74HC04) with AND gates (74HC08). Using this combination of integrated circuits led to the logic design shown in figure 8.

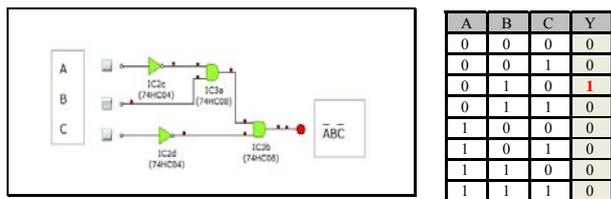


Figure 8: Logic Circuitry Diagram and Truth Table

The discriminating logic circuit design enabled the detection of the wavelength of interest which then needed to be interfaced to the SHIMMER and the sensor head. This was achieved in the manner outlined in figure 9.

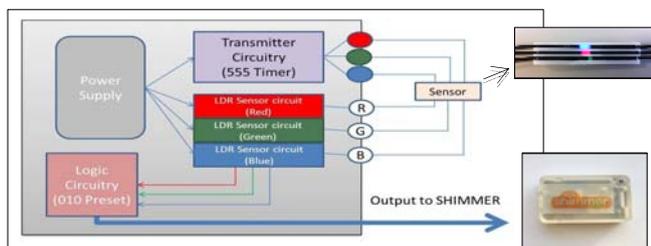


Figure 9: Circuitry Interfacing Block Diagram

After interfacing to the SHIMMER, the finalised circuitry was then placed in a waterproof housing with the sensors connected. Figure 10 displays the finished sensing housing with connectors for interfacing to the fiber and a battery power supply to power the electronics.

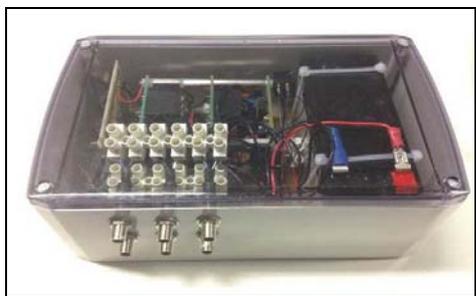


Figure 13: The Assembled Sensing Platform

## VIII. CONCLUSION

The system presented in this paper demonstrated the deployment of a novel fibre optic based sensing platform, capable of detecting minute changes in the level of impurity in a liquid. It was validated using chlorophyll and then the

sensing system was then interfaced onto a SHIMMER Mote and tested for overall functionality to ascertain whether the system was capable of warning a user of a presence of a particular pollutant within an aquatic environment. The importance of this type of sensing system is demonstrated by the growing international emphasis on the management of water quality and the need for robust, miniaturized, intelligent water monitoring systems capable of measuring local environmentally detrimental events.

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