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Design and development of low cost smart turbidity sensor for water quality monitoring in fish farms

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ABSTRACT

Turbidity monitoring is necessary in many cases and several sensors have been developed for this purpose. However, in some cases to quantify the turbidity it is not enough and its characterization is necessary. In fish farms, the increase of sedimentary or phytoplanktonic turbidity requires different actions to prevent further damages. For this reason, a sensor able to differentiate between turbidity sources is necessary. In this paper, a turbidity sensor able to distinguish different types of turbidity is designed, developed and calibrated. The sensor is based on the Beer-Lambert law and it uses four LEDs as light sources with different wavelengths. The sensing elements are located at 180° of the light sources and consist of a photodiode and a photoresistor, sensitive to infrared and visible wavelengths respectively. For the calibration process different turbidity sources were employed, *Isochrysis galbana*, *Tetraselmis chuii* and sediment. The results show that it is possible to determine the turbidity using the infrared light and to characterize the origin of that turbidity with the red light. An algorithm was created in order to create a method to process the data from each sample to obtain the turbidity, the origin of this turbidity and the concentration of the turbidity source. With this algorithm, we can create a smart turbidity sensor for water quality monitoring. Our main application is focused on monitoring the water input in fish farm facilities; however, this smart sensor will be useful in many other areas.

1. Introduction

The increase in human population and the changes of land use increase the turbidity levels in water (Fabricius et al., 2016). The monitoring of turbidity, for different purposes, has become an important issue. Turbidity is caused by suspended particles in water; these substances may be organic or inorganic. The inorganic ones are mainly composed of sediments, while the organic ones are mainly algae, microorganism, etc… (MPCA, 2017 and APHA, AWWA, WEF, 2012). Turbidity measurements are necessary for water quality monitoring. It is measured in natural resources, because of the negative effects on ecosystems (Smith and Davis-Colley, 2001). Moreover, it is measured in drinking water (Beaudeau et al., 2014), or in irrigation water (PNUMA, 2017). The principal effects of turbidity in the ecosystems are (I) reduction of visibility, (II) reduction of light penetration and photosynthesis process or (III) clogging of gills and other adverse physical effects on fish and eggs (Bruton, 1985 and Wilber and Clarke, 2001) among others. However, in some cases, the quantitative value of turbidity is not enough, because different types of turbidity may cause different effects. One example is in the fish farms, where the turbidity generated by sediments and the one generated by phytoplankton can require different actions to prevent further damages. For this reason, the characterization of turbidity is needed in the fish farms and in many other cases.

In fish farming, the increase of turbidity causes a reduction of fish performance. The effects of turbidity on fish growth and survival have been studied by different authors. Sutherland and Meyer (2007) maintained two fish species from 0 to 500 mg/l of sediment during 21 days. Their results showed that *Erimonax monachus* presented the highest SGR at 0 mg/l while *Cyprinella galactura* presented it from 0 to 50 mg/l. Ardjosoediro and Ramnarine (2002) maintained red tilapia during 56 days at different turbidity values, from 0 to 500 mg/l of clay. Fish presented higher weight at the end of the experiments when the level of turbidity was lower. The maximum survival rates were reached from 0 to 50 mg/l.

The possibility of monitoring the values of turbidity at the water input in the aquaculture facilities is useful in order to take different actions to prevent further damages in fish production. It can be especially valuable for inland facilities with open water circuit. In the facilities where larval and reproducers are kept those sensors are crucial to ensure the water quality in the production tanks. However, different types of turbidity cause different effects on fish. Suspended sediment

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may cause gill damage. *Cyprinella galactura* shows no gill damage from 0 to 50 mg/l of sediment, moderate damage at 100 mg/l and severe at 500 mg/l (Sutherland and Meyer, 2007). Au et al. (2004) founded a correlation on *Epinephelus coioides* between gill damage and suspended sediments. Hess et al. (2015) studied the changes in gills morphology on clownfish larvae exposed to suspended sediments. They conclude that fish exposed to 45 mg/l of sediments or more, had excessive mucous discharge and growth of protective cell layers. Moreover, in facilities with larvae culture, the technique of greenwater is widely used to increase the growth and survival of larvae (Faulk and Holt, 2005 and Palmer et al., 2007). This technique consists of adding algae in the water of the larvae tanks. However, this technique requires aeration to ensure the appropriate oxygen levels and to avoid the phytoplankton sedimentation. Recently, the use of clay has been studied as a substitute for phytoplankton in *Anoplopoma fimbria* (Lee, 2015 and Lee et al., 2017). However, the use of the greenwater technique requires the use of aeration to ensure that the oxygen concentrations do not decrease during dark periods. Different turbidity can cause different effects on fish and some specific actions must be taken. For this reason, it is necessary to have an automatic method to monitor the turbidity and to characterize it. Then, we can differentiate between two types of turbidity in fish farms, sedimentary turbidity, and phytoplanktonic turbidity. The worse possible conditions are related to the appearance of phytoplankton turbidity during dark periods (night or dark photoperiod in the tanks). In those conditions, the phytoplankton starts to consume the oxygen in the water and may require the activation of the aeration in order to prevent hypoxia conditions in the tanks. Moreover, some algae species may produce toxic products.

There are other areas where characterize the turbidity may be useful. The possibility to detect and track phytoplankton blooms is interesting in some ecosystems, Parra et al. (2015) proposed a similar system with hydrocarbons. The algae blooms formed by some species are considered as an abnormal situation in ecosystems that can cause eutrophication. Moreover, in some cases, those algae blooms can produce water pollution because of the production of some toxic compounds by the algae. Besides, in dark conditions, the algae blooms may consume high quantities of dissolved oxygen.

The most common method for measuring turbidity is the optical sensors. Optical sensor works by emitting a beam of light and detecting the amount of light that reaches the detector. Three techniques exist for optical sensing, according to the measuring angles. If the angle is 90° it is called nephelometric, if he the angle is 180° it is called absorbimeters and if the angle is found between 90°–180° it is called backscattering (Bin Omar and Bin MatJafri, 2009). Different techniques are applied to measure different turbidity levels (Lambrou et al., 2009). Takaaki et al. (2012) used 5 stations with optical sensors to monitor sediment transported in rivers. Schoellhamer and Wright (2003) used optical turbidity sensors for continuous measurement of suspended solids discharged in rivers. Stubblefield et al. (2007) used nephelometric turbidiometry for determining suspended solids in a lake. The Secchi disk, a traditional method, consists of the introduction of a disk into the water, the distance in which we stop observing the disk is inversely proportional to the turbidity (Lee et al. 2015). However, this methodology is not suitable for continuous monitoring. There are other methods such as acoustic sensors or the use of satellite images. Chanson et al. (2008) and Ward et al. (2013) used acoustic methods to measure the turbidity in rivers. Güttler et al. (2013) and Zheng et al. (2016) used remote sensing in rivers and lakes. The commercial turbidimeters that are currently in the market have two problems. The first one is the high price of the sensor, which may become prohibitive for many applications. The second one is that commercial sensors do not differentiate the type of turbidity (sedimentary or phytoplanktonic). Those are the current gaps in the commercial devices that are avoiding the use of turbidity sensors for monitoring in many applications.

In this paper, a low cost smart turbidimeter is designed and developed. Our smart turbidity sensor will be capable of differentiating phytoplanktonic turbidity from sedimentary turbidity. This new turbidimeter is based on optical methods. Different light-emitting diodes (LEDs) with different wavelength (i) infrared (IR), (ii) green, (iii) yellow, and (iv) red are used as a light source. Two light detectors are used, a light dependent resistance (LDR) to detect visible light (180°) and photodiodes for detecting infrared light. These light-emitting diodes (LEDs) are powered by a voltage of 4.5 V. The proposed sensor offers two improvements compared to existing commercial sensors: (i) the lower cost of the sensors and (ii) its capability to differentiate sedimentary turbidity from phytoplanktonic turbidity. This sensor will help us to control sensitive areas, monitor of fish farms. Moreover, it can be used in other activities or environments where a bloom of algae can be produced or the turbidity have to be controlled.

2. Material and methods

In this section, the material and methods are presented. First, the background about the light absorption and the turbidity is detailed. Then, the design and development and price of the turbidity sensor and the origin of turbidity samples are described.

2.1. Background

In this section, the background of optical sensors is shown. Turbidity is defined as the loss of clarity in water, light may be absorbed, reflected or dispersed (Bin Omar and Bin MatJafri, 2009). Moreover, this parameter is related to the Beer-Lambert law Eq. (1) (Postolache et al., 2002). The Beer-Lambert law quantifies the transmitted light (*It*), as a function of the light intensity of a source (*Io*), the absorption coefficient per unit length (*a*), the turbidity (*t*), and the length of the light pass (*l*). Form one side, absorption coefficient, and turbidity are related to the turbidity of the water. By the other side, the intensity of a source and length of the light pass are related to the measurement instrument. The value of (*It*), can be expressed as a function of the scatter angle (θ), the particle size (*r*), the wavelength(λ), and the optical properties of the particle and the medium such as the refractive index (*n*) Eq. (2), (Postolache et al., 2002).

$$It = Io \times e^{-(a*t)l} \quad (1)$$

$$It = Io(\theta, \lambda, \mathrm{r,n}) \quad (2)$$

2.2. Design and development of the turbidity sensor

In this subsection the design and the development of our turbidity sensors are detailed. For its design, several conditions must be met. These include low cost, low battery consumption, low maintenance and easiness to clean. As we concluded in the previous section, the most suitable option is the use of light beam for turbidity detection. In the majority of papers, authors use IR light source and IR light detectors. Nevertheless, as the developed turbidity sensor must be able to distinguish between different turbidity sources, more than one light source will be included. One IR and three colour light sources, green, yellow and red. The 5 mm IR LED employed is the TSHG6200 (Vishay, 2017a). It has a peak wavelength of 850 nm. The 5 mm colour LEDs sources have a peak wavelength of 612–625 nm (the red one), 581–594 nm (the yellow one) and 562–575 nm (the green one). They are the TLLR4400 (Vishay, 2017b).The light receptors used in the sensor are the IR photodiode and the Light Dependent Resistor (LDR) is sensible to a visible light range, the used one is the NSL 19M51 (LDR, 2017). The LDR changes its resistivity depending on the amount of light that impacts on the sensitive part. The higher light intensity, the lower LDR resistance. The employed IR photodiode presents high speed and high radiant sensitivity. Its sensitivity range goes from 790 nm to 1050 nm and the peak appears at 950 nm. The photodiode is manufactured by Vishay, which code is BPW83 (Vishay, 2017c). The photodiode operation is the