Development of Optical Sensor to detect Industrial Oil in Agricultural Irrigation System

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***Abstract*— The increase of the industrial sector and the use of mechanical devices in agriculture causes the increment of oil discharges in water bodies that are used to irrigate agricultural lands. In this context, precision agriculture becomes a critical way to solve these problems. In this paper, we propose an optical sensor to detect and monitor the quantity of oil in the agricultural irrigation system. The sensors use different colour light sources (white, yellow, blue, green, orange, and near-infrared). Moreover, a photoresistor and photodiode are located at 0º and 180º of the light source to measure the light dispersion. This prototype will be part of a wireless sensor network that allows obtaining the values in real-time in river channels. We experimented using different oil concentrations, between 0 and 0.2 ml oil/cm^2. In addition, we analyse the output voltage changes between the different light sources for all oil quantities. The results show that the lowest difference is found for the white colour with 0.025 V. Then, the yellow and blue light sources obtained a change of 0.089 and 0.075 V respectively. On the other hand, the highest voltages are found for the green and red clours, with 0.29 and 0.39 V. The mathematical models of the bests Light Sources are calculated, obtaining the correlation coefficients of 0.9604 in the red light and 0.8647 in the green light. Finally, we perform a multirange analysis with the values of the different light sources, verifying that the red and green light sources have the most reliable values.**

Keywords—Ligth source, light reflection, light detector, oil detection, precision agriculture.

I. INTRODUCTION

The world population doubled from 1970 to 2015, causing an increase in industrial activity, rising the pressure on the agroecosystems [1]. The presence of contaminants in the water of the agricultural irrigation systems is one of the main problems that farmers face. These pollutants can be introduced in many ways, such as illegal discharges of oil caused by industry, or due to the bad habits of farmers. Ditches are considered as one of the most commonly polluted water bodies. This water mass is used as a water resource for the irrigation system. One of the pollutants in the irrigation water is the industrial oil which comes from car workshops that do not do the treatment of the used oils. Another source is the repairs of the agricultural machinery.

The use of oil-polluted water for irrigation could decrease the production and quality of the harvest [2], which might cause scarcity of agricultural products and generate significant economic losses to the farmers. The main ones are (I) accumulation of pollutants in the soil, (II) depletion of the availability of nutrients, and (III) reduction in the number of microorganisms [3]. Furthermore, the oil produced in industrial processes and large machines used in agriculture usually contains heavy metals [4]. These heavy metals are harmful to the environment and humans. Likewise, the introduction of these compounds in the crops produces the insertion of toxic elements in the agro-food system, causing problems for human health.

Some industries discharge their waste to the environment, where the pollutants reach the river, ditches, and groundwater used to irrigate the crops. This irresponsibility might cause a decrease in land production, damage in the environmental systems as well as diseases in humans. In this context, technological advantages are too scarce, and it is difficult to correlate the oil discharges with the prevalence of diseases. The farmers are aware of the damages that produced these sort of compounds in agriculture. Moreover, the available techniques to control the quality of the agricultural irrigation water are based on sending water samples to the laboratory where the chemical analyses are performed. Nowadays, the laboratories are vital to detect the contaminants in the agricultural irrigation system, though relying on their analyses have several disadvantages. These analyses do not allow having continuous monitoring, and the performed analyses have a high cost. In this frame, the use of a sensor which can continuously monitor the presence of pollutants in water is emerging. Those sensors allow continuous control of the water quality; while reducing the costs of the water analysis. In the last few years, the concept of Precision Agriculture (PA) has been grown [5]. This new method is based on the introduction of technology in the agricultural sector (including sensors, remote sensing or artificial intelligence, among others). PA improves the management strategy based on the analyses of gathered data. These data can be used to estimate the variability of the cropping systems and to improve efficiency, productivity, and quality of the agricultural activity. Hereupon, different sensors to monitor agricultural irrigation water are developed, such as a conductivity sensor to monitor the fertiliser in the water [6] or soil moisture sensors [7].

In this paper, we propose an optical sensor based on light reflection to monitor the amount of industrial oil in water bodies used for agricultural irrigation. We use the engine oil of a car as an industrial oil source, which can be one of the most common oil sources in the agriculture areas. The developed sensor is based on light-emitting diodes (LED), including the visible and infrared spectrum. A light-dependent resistor (LDR) and a photodiode are used to measure the quantity of light that they received. The LDR decreases its resistance when the light increases. With regard to the LEDs, we locate five colour LEDs at the bottom of the glass bottle (red, green, blue, yellow, and white) and one Near-infrared (NIR) LED. Concerning the light detectors, a pair of LDR and photodiode is located at 180º of the light sources at 12cm, and another pair of detectors are located at 360º, close to the light sources. Samples of water with different quantities of pollutant are used to test the performance of the proposed sensor.

The rest of the paper is structured as follows. The related works are presented in Section II. The proposed sensor is described in section III. Then, Section IV details the methodology used to evaluate the performance of the sensor. In Section V, the obtained results are discussed. Finally, the conclusion and future work are outlined in Section VI.

II. RELATED WORKS

In this section, we present the different related work in water quality monitoring. After analysing the current proposals, we detail the advantages of the proposed sensor.

Laneve et al. [8] suggested the use of a Specific Absorption Rate (SAR) system combined with a multispectral sensor like Moderate Resolution Imaging Spectroradiometer (MODIS) to detect oil in water. In this work, the results achievable through the development of dedicated algorithms for automatic image processing from MODIS data, and a method to classify and describe oil spill events are presented. Furthermore, Klemas [9] used remote sensing, satellite and aircraft, for tracking the oil spills at various resolutions over broad areas and using different frequency intervals. The satellite provides the possibility to drift prediction models, such as oil spill locations. They concluded that the model required a vast range of environmental data to predict the oil spill trajectory. Iler et al. [10] applied an Integrity Applications Incorporated, which collected electro-optical polarimetric imagery (PI) to evaluate its effectiveness for detecting oil in water. They obtained the data at multiple sun angles for vegetable oil and crude oil to demonstrate PI sensitivity to different liquids and collection geometries. Their conclusions highlight the optimal behaviour of the system and the possibilities of applying it to detect agricultural runoff or effluent from industrial facilities. The aforementioned detection methods are not the best options for oil detection in an agriculture irrigation channel. The main limitation of those systems for the proposed problem is its low spatial and temporal resolution. Moreover, those are high-cost systems. Besides, there are high-cost systems. In this context, it is necessary to evaluate the systems based on sensors rather than remote sensing systems

Other authors used optical sensors for monitoring water quality. Yeh et al. [11] studied the application of LEDs in optical sensors and chemical sensing devices for the detection of biochemical, heavy metals, and environmental nutrients. This system worked in the range of Ultra Violet (UV) and Infrared (IR). They found that the less used LEDs are the orange, yellow, and green ones. The research concluded that LEDs had become the prominent light sources of chemical sensors. A. MacLean et al. [12] presented an optical sensor which was able to detect the presence of hydrocarbon spills. The used sensor contained liquid-swelling polymers that convert the swelling into a micro bend force on an optical fibre when activated. This sensor was able to locate 1-meter-long spill events with a location accuracy of 2.5 m over a range of 2 km. Finally, they concluded that the sensor would able to operate in adverse environmental conditions. A novel modular, mid-infrared, evanescent wave fibre optic sensor for the detection of hydrocarbon pollutants in the water had been designed, constructed, and tested by R. P. McCue et al. [13]. Their design utilised simple, low-cost production of the rugged field-based sensor. Besides, they use a fibre optic sensing element, coated with an analyte-enriching polymer that concentrates the analyte in the sensing region. Then the output signal of the optic fibre is filtered at an analyte absorption peak and coupled to a thermopile detector whose signal is read into a computer for analysis. The results concluded that the system could be used as a pollutant detector, with benzene quantified down to 500 ppm using a PVC polymer coating. The sensors described in this paragraph are not useful for our purpose, because they used chemical compounds that cause the necessity of maintenance, increasing the cost of the system. Therefore we must focus on sensors which are composed of simple optical methods based on light absorption or reflection of clean water and polluted water.

On the other hand, L. Parra et al. [14] proposed an optical sensor for hydrocarbon detection in ocean water. The presented sensor is composed of LEDs as a light source and photoreceptor as a light detector. They performed several tests using light sources with different wavelengths (violet, blue, green, orange, red, and white). Their results concluded that the white colour provides the best results. This study is performed only to verify the presence of hydrocarbon in water, but the authors do not detail the capacity of their proposal to quantify it.

In this section, we summarised the existing proposals of different methods to monitor and detect oil or hydrocarbon discharges. Besides, we identify the main limitations of different methods, and justify the need for using simple systems based on light emission and detection as it was done in [14]. In addition, we identify that turbidity can affect the measure took by the sensor. Our prototype is an optical sensor which can monitor in real-time the water to detect any oil discharges to the irrigation channels. As far as we know, there are no other papers in which optical sensors for measuring oil in the agriculture irrigation system is presented and calibrated.

III. PROPOSAL

In this section, we show the proposed sensor and the microcontroller that we propose to use to control its operation. In addition, we outline a possible scheme to locate the sensor into the irrigation channels, and an operation algorithm if the sensor is integrated into a wireless sensor network for PA. The sensor is based on different LEDs to measure oil presence in irrigation water. The objective of this prototype is to detect the presence of oils in the water and send alarms to the different water agents to inform them about detected illegal dumping. Furthermore, this information can be used to avoid irrigating the fields with polluted water.

This sensor will be part of the Smart wireless sensor network to detect and purification water salinity and pollution for agriculture irrigation (SMARTWATIR) final monitoring system.

A. Proposed sensor

In this subsection, we describe the physical characteristics and the crafting of our prototype.

We use six different LEDs as light sources (yellow, red, blue, green, white, and infrared). In addition, we locate two Light Decreasing Resistances (LDRs), sensible to visible light spectrum, and two photodiodes, which can sense the infrared light, at 0º and 180º of the LEDs. The LEDs serve as light sources, while LDRs and photodiodes are used to detect the amount of light, which is dispersed, reflected, absorbed, or passes through, the water column. In *Fig. 1* we can observe the working diagram of our sensor. The LEDs emit light that insides the oil layer. As one portion of this light crosses the oil layer, another part is reflected. The LDRs and photodiodes measure the light that crosses the oil layer (180º respect the LEDs) or the reflected light (0º respect the LEDs).

The size of the LEDs is 5 mm for the visible LEDs, and 3 mm for the infrared LED. All of them are the diffused-light type with function voltage of 1.8-2V for the red and yellow LEDs, 3-3.4V for the white, green and blue LEDs, and 1.5V for the infrared LED. Likewise, all LEDs have a vision angle of 20º, and a function current of 20 mA. The model of LDR used is NSL-19M51 (5 mm), and the photodiode is the TLLR4400 (3 mm). Moreover, the prototype is crafted in a PVC pipe of 50 mm of diameter with a thickness of 5 mm. In *Fig. 2,* we can observe the initial design of the prototype. The LEDs are located close to the wall of PVC, then an LDR and photodiode are situated nearby the light source. Above the sensor, we locate a glass that contained the water with the oil, which must be monitored. In *Fig. 3,* the crafted prototype is presented.

To read the values of LDR and photodiode as a voltage, we use a voltage divider. In voltage divider, there are two resistances, one resistance is the photodiode/LDR, and the other is a fixed resistance. With the values of resistance of LDR/photodiode, we calculate the value of the fixed resistance. We use the solver tool of Excel for determining the best-fixed resistance that meets the maximum voltage difference between the minimum and the maximum oil quantity tested. We use equation 1 for this purpose, calculating the output voltage (Vout). In an equation, V_{in} is the voltage at which the LDR and photodiode are powered. We establish a value of 3.3V to power them. The value of $R_{circuit}$ is the value of the resistance that we calculate, the fixed resistance. Finally, R_{LDR} is the value of the resistance of the LDR (in the range rehearsed).

$$Vout = (V\_in * R\_circut)/(R\_circuit + R\_LDR) \tag{1}$$

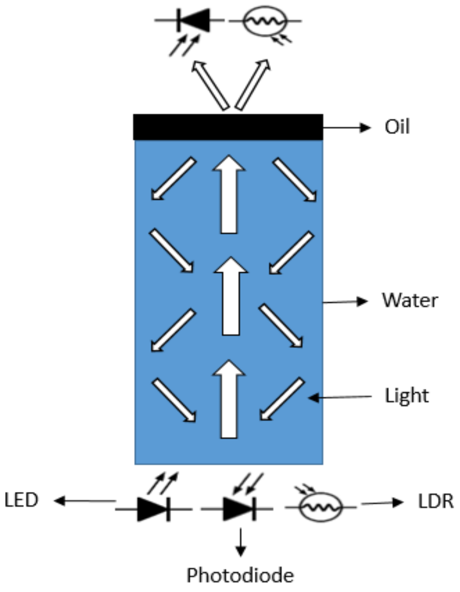

Fig. 1. Sensor working diagram

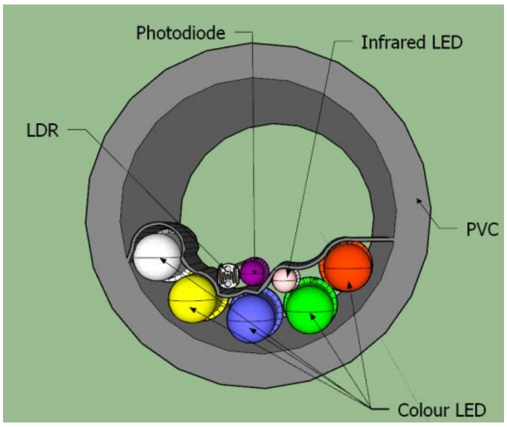

Fig. 2. Designed prototype.

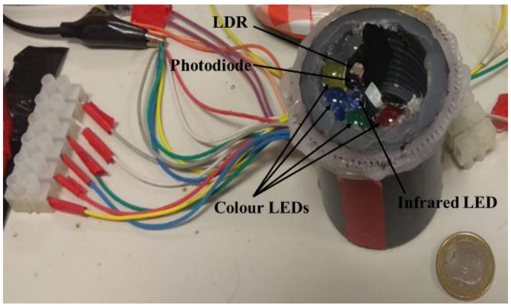

Fig. 3. Used prototype.

B. *WiFi node*

In this subsection, we show the wireless node that we propose to use with the prototype in the future deployments. The functions of the node will be read the Vout of LDR and photodiode, sent data, and powered the LEDs.

We propose to use a microcontroller ATmega328p with a module ESP8266 to WiFi. ATmega328p is a low-cost and easy to program node, compatible with Arduino IDE. This node has outputs of 5V and 3.3 V. We can use the 5 V output to power the LEDs and the 3.3 V output for feed the LDRs and photodiodes in the future. The antenna and microcontroller are located in a waterproof box out of the water due to the WiFi is attenuated in the water.

C." Future deployment.

In this subsection, we show a proposal for the future deployment of the tested prototype in the environment.

The prototype must be encapsulated for preventing damage from animals, obstructions due to solids in water, etc. The encapsulation might decrease the light input and can affect the measurement. The prototype has openings at the top of the encapsulation to allow the entrance of the water with oil. Our prototype can be hooked on the wall of the channel. The microcontroller, batteries, and WiFi antennas are in a waterproof box above the water level to ensure the WiFi connectivity. In *Fig. 4* we can observe the proposed scheme for the deployment of our prototype in the irrigation channel.

D." Algorithm.

In this subsection, we explain the function of the algorithm of our sensor.

The algorithm is summarised in *Fig. 5*. First, the threshold values of used industrial oil and turbidity are set (THx). Next, the sensor determines the presence of oil in the water (on the LEDs and read the LDR/photodiode). If the value of oil is lower than THx, the sensor waits a specified period (t1) to get back into operation. On the other hand, if the presence of oil is higher than the THx, turbidity sensor [15] started working. The turbidity sensor is starting to prevent false positive of oil presence. If the turbidity level is below the set value, it indicates the presence of oil in monitored water. If the systems determine the presence of oil, the node sends an alarm using the WiFi antenna, and stores the data in its memory. Instead, if the value of turbidity is higher than the value set, it can indicate a false positive and data is stored. We have established the limit of 3600 record stores in the node. When data is stored, the system adds +1 to a variable (clock). If the variable clock is 3600, the system sent data and removes internal memory. Finally, the system waits for a time (t2) for starting a new measure.

IV. TEST BENCH

In this section, we show the used methodology to obtain the data required to evaluate the performance and calibrate our prototype. In addition, we display the characteristics and functioning of the proposed prototype.

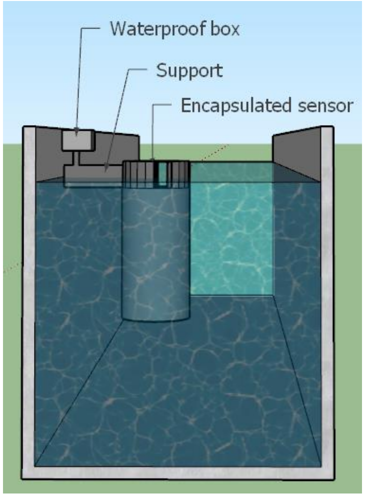

Fig. 4. Deployment of the sensors in the Irrigation channels for agriculture.

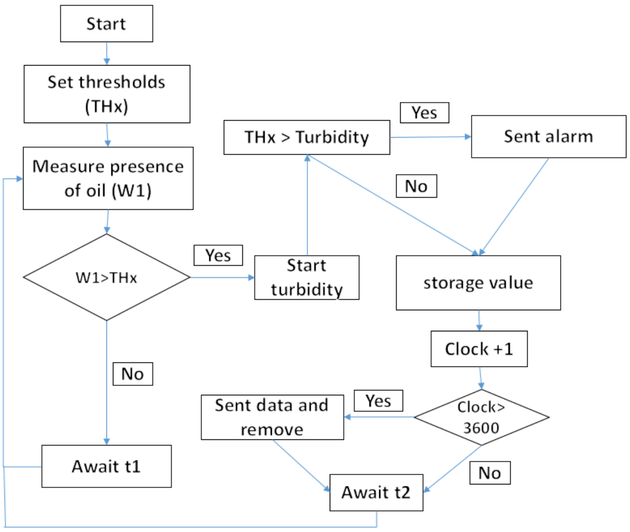

Fig. 5. Developed Algorithm

We use an AC power supply model FAC-662B to power the LEDs with a current of 5 V and 0.3 A. Each LED has a resistance of 470Ω with a tolerance of 5% between the power supply and the LED. We carry out the measurements by turning the LEDs sequentially. The sequential order to light the LEDs is yellow, red, blue, green, white, and infrared. As the LDRs have a delay, we wait 5 seconds to take the measurement. The measurements are taken in triplicate. Once we have already gathered the resistance values, we turn off the LED. Then, we turn on the following LED.

We measure the resistance of the LDRs and photodiodes with a tester (Tenma 72-2600 [16]). The resistance of the LDR decreases when the light exposure increases and the resistance increases when the light intensity decrease. Otherwise, the photodiode works oppositely than LDR.

The industrial oil used in this paper has been obtained from a mechanical workshop. The oil is a 0W-30 used for a fuel car during 10.000 km, which can be one of the possible oil sources in the farms. We use this sample to recreate a similar scenario of dumping in an agricultural irrigation system. Notably, the oils, which have remained a long time in vehicles, are the more pollutant ones.

The samples are introduced in a glass cylinder with a diameter of 8 cm and 16 cm in height. We introduce the water sample up to a height of 12 cm (approximately 600 ml). After each measurement, we add a small amount of oil in the sample of water. We test with a volume of 1, 2.5, 5, 7.5, and 10 ml of oil in the sample of water. Since the oil is not mixed with the water in the irrigation channels, due to the different densities and polarities, these volumes correspond to the concentration of 0.02, 0.05, 0.1, 0.15, and 0.2 ml oil/cm^2 on the surface of the water.

V. RESULTS

In this section, we analyse the results of our prototype for detecting the presence of industrial oil in water.

After gathering data and analyse the results, we observe that the values of the resistance in the LDR and photodiode placed at 180º of the light source are not constant. Since we recreate the water movement expected in the irrigation channel, the oil stains do not remain quiet over the surface water. Due to this movement, oil spots cover the light of the LDR and the photodiode intermittently. Due to this effect, the resistance values are not constant.

Furthermore, in the case of infrared LED, the value of the resistance of photodiode at 360º varies from 7980 to 7907 kΩ in the concentrations of 0 and 0.2 ml Oil/cm^2 respectively (in the rest samples the resistance is between these two values). With these resistance values, the voltage difference after the voltage divider is almost null. For this reason, we discard the use of infrared LED.

Therefore, we are going to focus on the values of resistance in the LDR at 0º for the different colour lights. With the values of resistance of LDR and Eq. 1, we can obtain the most appropriated resistances to be used the voltage divider (Table 1*)*.

The calculated values of Vout for the different LEDs can be observed in *Fig. 6*. The obtained Vout with the 5 LEDs included in *Fig 6* presents a similar behaviour linked to the changes in the pollution presence. When the pollution level increases, the Vout of the LDR rises. It is caused by the higher light reflection on the oil surface compared with the water surface. If we study the different LEDs independently, we can see that the white LED has the lowest Vout difference between maximum and minimum oil quantity (0.025 V). This reduced voltage difference implies a low resolution of the future sensor. The difference with the white LED is much lower than with the other light sources. The yellow and blue LEDs present a difference in the Vout between the most and the less polluted samples of 0.089 and 0.075 V, respectively. On the other hand, the green and red LEDs have a higher difference with 0.29 and 0.39 V.

As the red and green LEDs have the highest voltage difference, and they can differentiate between 0 to 0.1 ml oil/cm of industry oil, we select them. Now, we detail the mathematical equations that model the concentration of oil (cm^2/l) and Vout. The mathematical model between the Vout and the presence of industry oil is presented in (2) and (3). Equation 2 is the mathematical model for the red LED, and (3) is the mathematical model for the green LED. The value of R2 (Coefficient of determination) is 0.9604 for (2) and 0.8647 for (3).

$$Vout\ Red\ LED(V) = 1/(0.553557\ +\ 0.357183 * \sqrt{(Oil\ ((cm)^\wedge 2/l))}) \tag{2}$$

$$Vout\ Green\ LED(V) = 1/(0.574694\ +\ 0.245706 * \sqrt{(Oil\ ((cm)^\wedge 2/l))}) \tag{3}$$

To obtain more reliable data from our prototype, we applied a Single ANOVA statistical procedure to the gathered data. Moreover, we reach two indicators: Reason-F and Value- P. The first one is used to determine whether from among a group of independent variables, at least one ability to explain a significant part of the variation of the dependent variable. Otherwise, Value- P is required to know if the obtained results are produced by random sampling, or they are statistically significant. When the Value-P is lower than 0.05, we can affirm that the observed differences are caused by differences in the samples and not to the randomness of the data.

TABLE 1. VALUE OF SELECTED RESISTANCE FOR THE DIFFERENT LEDS.

LED	**Resistance (kΩ)**
Yellow	75.5
Red	429.6
Blue	49.6
Green	70.8
White	11.1

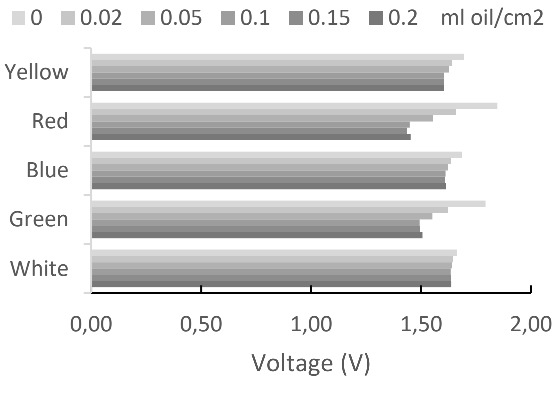

Fig. 6. Values of Vout of the LDR in the different LED colours

TABLE 2. RESULTS OF STATISTICAL ANOVA TESTS TO ANALYSE MEASURED VALUES.

LEDs	**ANOVA**	
	Reason- F	***Value-P***
White	354.28	0.0000
Green	1745975.11	0.0000
Blue	5732.62	0.0000
Red	175727.47	0.0000
Yellow	7110.87	0.0000

In this context, Table 2 presented the results of these two indicators for the five different wavelengths. Basing on the results shown in Table 2, we can confirm that all the tested light are capable of distinguishing and quantifying the amount of oil. Nevertheless, further analyses are required to evaluate if it is possible to distinguish between all tested concentrations of pollutant.

We performed a multirange analysis with the values of the different LEDs. In *Fig. 7*, we classify the different range of industrial oil according to the different groups with an interval of confidence of 95%. The value of the blue bar is the average of the three measurements taken. The values of the black lines are the standard deviation for each sample. Finally, the letter indicates the group in which they are classifying with a 95% confidence interval. The groups are performed according to the Least significant difference of Fisher. With the obtained data of Vout with the yellow LED, it is possible to differentiate all the tested oil concentrations. Nevertheless, we can see that the value of Vout in 0.15 ml oil/cm^2 does not follow the same trend that the other gathered data (this value increases instead of decreasing). This trend is also observed in the other series of data. In addition, the yellow LED has lower voltage changes between the different concentrations than the red and green LEDs. In the case of the blue and white LEDs, the gathered Vout cannot be used to differentiate in concentrations higher than 5 ml of industry oil. With regards to the data gathered with the blue light only 0.1 and 0.2 ml oil cm^2 are in the same group. With respect to the white light except for the 0.1 and 0.15 ml oil cm^2, all concentrations are in different groups. Finally, in the case of the data obtained with the red and green light, all concentrations tested are classified as different groups. Nonetheless, in concentrations higher than 0.1 ml oil/cm2, the Vout values remain similar for the green and red LEDs. The Vout obtained with the red and green LEDs have a difference between the maximum and minimum tested pollution levels up to 0.27 V. Though, the red light has a higher correlation than green light. Moreover, with the data gathered with the red LED can difference between 1 and 2.5 ml of industry oil, while the data from the green LED cannot do it.

VI. CONCLUSIONS AND FUTURE WORK

The detection and quantification of oil pollution in water of irrigation channels is vital to ensure proper water quality in PA. The physical sensors based on the optical phenomenon (such as light absorption, reflection, refraction, etc.) are the most appropriated method for water monitoring.

In this paper, we developed and calibrated a sensor for monitoring the presence of industrial oil in the irrigation system. Our prototype is based on LEDs as a light source and LDRs and photodiode as light detectors.

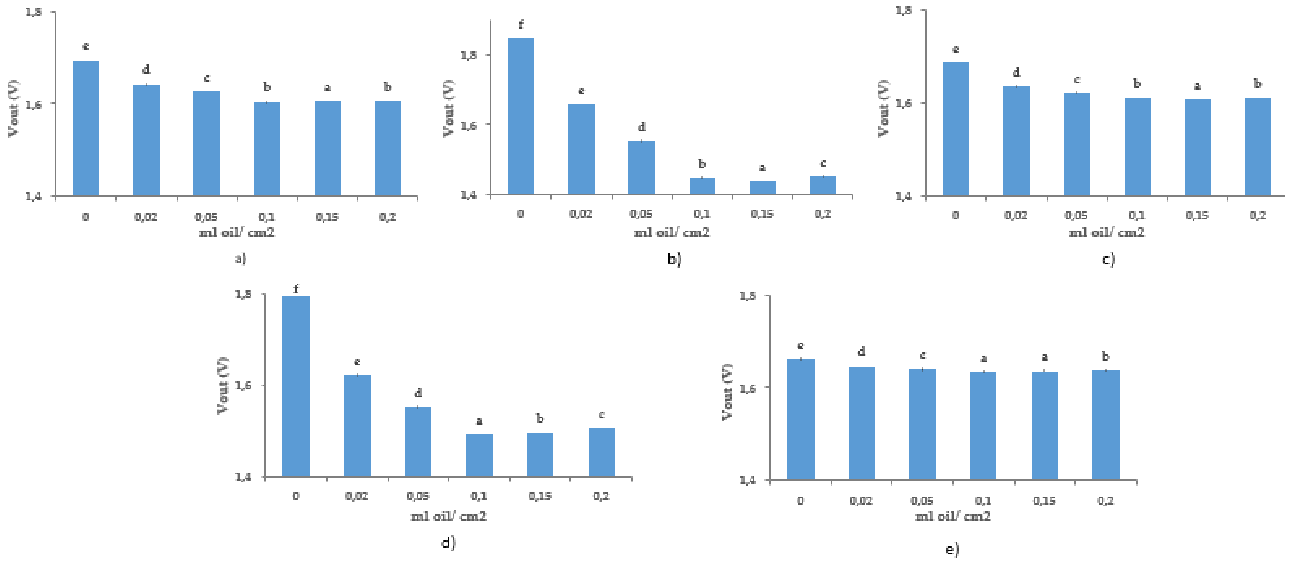

Fig. 7. Voltage out of the different LEDs, groups classification with a confidence interval of 95% and standard deviation. (a) Yellow (b) Red (c) Blue (d) Green (e) White.

We discard the use of LDR at 180º to the light source. The presence of oil stains on the surface causes considerable changes in the light that affects the light detectors at 180º. Nonetheless, the data gathered with light detectors placed at 360º from the light source offers reliable information. The infrared light sources were discarded due to its low interaction with the tested samples. Among the different LEDs tested, the bests results are gathered with the red LED.

In future work, we will test our prototype with different highs of water, used industry oils of different sources, and not used industry oils. Moreover, we will evaluate the effect of turbidity in our measurements, being useful to validate the obtained data of optical oil sensor. In addition, we will incorporate neuronal networks to optimize the sensor performance, to detect different compounds.

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