Design and Implementation of Fibre Optic Sensor for Soil Moisture Detection

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***Abstract*—In this paper, the design and implementation of a fibre optic sensor system for moisture detection are reported. The basic concept of a fibre optic sensor is to detect any changes in the intensity of light that travels inside the fibre. The paper describes the sensor design, the experimental setup and four examples of sensor prototypes. A phototransistor is used to detect light in the fibre optic, while Arduino nano is utilised to read the output data. Four different sensors with different length and width are employed to detect the level of soil moisture. The effects of sensor dimensions on the soil moisture detection are studied. The most stable response provided by two sensors, one with 1-inch width and 0.63 inches length and the other design is with the dimension of 1- inch and 0.87 inches length.**

***Index Terms*—Fiber Optics; Optical Sensor; Soil Moisture Monitoring; Humidity Monitoring.**

I. INTRODUCTION

The measurement of moisture condition or environmental humidity is crucial in a large number of applications, ranging from health monitoring, climate and environment monitoring, oil and gas industries, agriculture and various others [1-5].

Soil moisture sensor is a very beneficial device in the government agencies and private companies where monitoring, quality improvement, and failure detection are the primary concerns, including flood control, soil erosion, slope failure, reservoir management, and water quality. For instance, by employing the soil moisture sensor through evaporation and plant transpiration, the exchange of water and heat energy between the land surface and the atmosphere can be controlled. Soil moisture can be used for reservoir management, early warning of droughts, irrigation scheduling and crop yield forecasting as well [6-8].

Soil moisture is the volume of water contains in the soil. The water is held within the soil pores. Soil water is the major component that contributes to the plant growth. Too much water remains in the soil as a thin film and prevents the plant from breathing. Soil water dissolves salts, which is vital as a medium for supplying nutrients to the growing plants.

To date, there are various types of technologies of soil moisture sensor available in the market, including resistive, capacitive and hygrometric sensors [9-11]. These conventional electric sensors experience several drawbacks, such as relatively high cost, the urgency for maintenance and unsuitable to be used in hazardous environments [12-14]. Optical fibre sensors have found to overcome these disadvantages with extra excellent features, such as compact, lightweight and reducing the multiple cabling used in the traditional electronic sensing [15-17].

This paper involves the development of soil moisture sensor based on the fibre optic. Plastic or polymer optical fibre (POF) was chosen due to their low cost and flexibility [20]. POF is often called as consumer optical fibre because of the affordable price. POF has been considered as a viable alternative to other technologies owing to rapid development in polymer technology and applications [21]. Basically, the basic concept of a fibre optic sensor is to detect any changes in the intensity of light that travels inside the fibre. The variations of light intensity can be exploited for many different applications by merely changing the nature of the sensitive coating [22]. The light is typically confined inside the core of the fibre by the cladding coating. When the cladding coating is removed, the light can leak out from the fibre core. It happens when some compound substance or material used to wrap the fibre is removed.

This paper proposes a simple and inexpensive plastic optic fibre based sensors to monitor the condition of soil moisture. Four types of sensors with different widths and lengths are designed to study the responsivity to water moisture. The output of the sensors is connected to the control and display unit in order to investigate how an entire sensor system can be designed to satisfy the demands of users.

II. EXPERIMENTAL SETUP

The measurement set up is comprised of a transmitter circuit, a fibre optic sensor, a receiver circuit and controller, and a display unit to capture and process the information, as depicted in Figure 1. Simple LED is used to transmit the light and IF E96 phototransistor is used for operating at wavelength 530nm, respectively, to read the value from the sensor. The photodiode functions as a light detector, which involves the conversion of light into voltage or current, based on the device's mode of operation. It consists of built-in lenses, optical filters and has either small or large surface areas. For the controller and display output, Arduino Nano is used to display the value of humidity/moisture sensor.

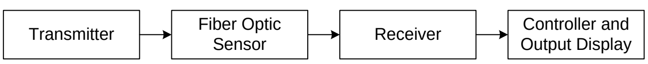

Figure 1: Block Diagram of the Soil Moisture Sensor System

Figure 2 shows a simple circuit connecting the receiver circuit to the Arduino Nano. The central part of the system consists of Atmega 328 microcontroller, which is powered by a 5V power supply. ISIS from the Proteus software was used to analyse the circuit, while ARES from Proteus was utilised to transform the circuit layout to the printed circuit board (PCB) layout.

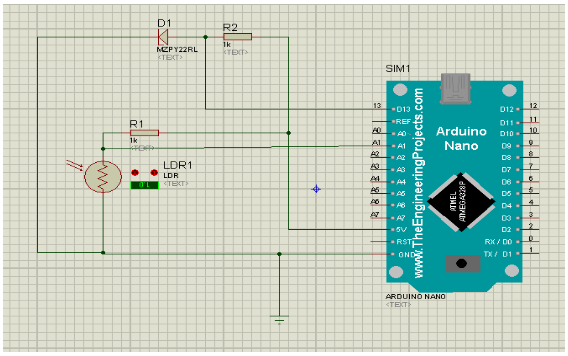

Figure 2: Schematic diagram of circuit connection to Arduino Uno

Figure 3 portrays the proposed design of the fibre optic sensor for moisture monitoring. The core material used for the optical fibre is polymethylmethacrylate (PMMA) that allows the speed of data transfer of 1 GB/s, which is much better or faster than the traditional copper wire. In order to deploy a fibre optic-based sensor, whose transmittance is affected by the materials surrounding the fibre itself, the fibre core is exposed so that the evanescent field is in contact with the surroundings. Once the buffer coating and cladding is removed, the exposed fibre optic is covered with plaster of Paris and protected by the plastic cover at the outer layer. Plaster of Paris will absorb moisture from the soil around it. In the presence of water, the uncoated polymer optical fibre will experience a refractive index change, where the light penetrating the fibre can be scattered out. The reflected light signal will indicate the decrease of the effective light intensity, thus induces a change in the transmitted power to the receiver.

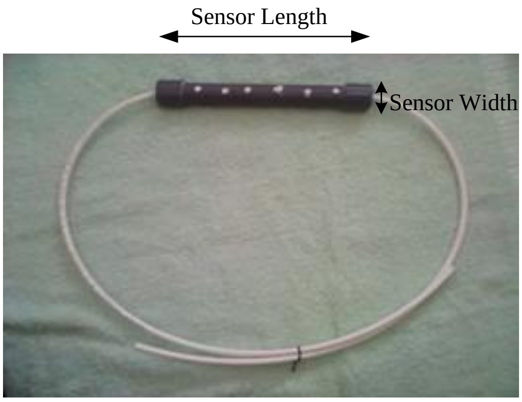

Figure 3: Soil moisture sensor design

The measurement setup of the fibre optic sensor is shown as in Figure 4. It consists of fibre moisture sensor, along with POF, which was inserted into a bowl where the water will be poured in. One end of the POF was connected to the transmitter circuit, which includes an LED as a light source and the other end was connected to the receiver circuit. The light signal received at the receiver will be converted to the electrical signal by the controller unit and will be sent to the display unit where the response can be monitored through a personal computer.

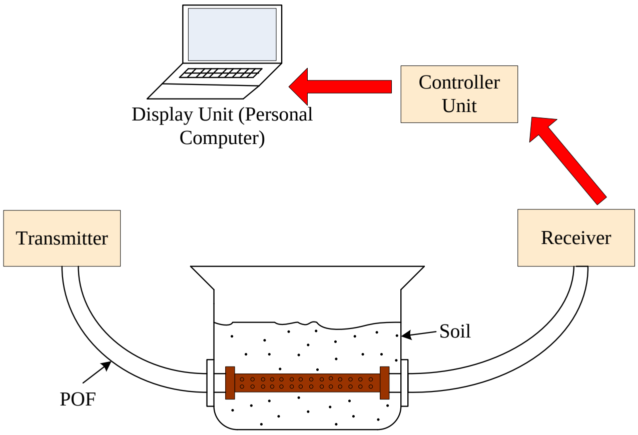

Figure 4: Setup used for sensor characterisation

There are four different fibre optic sensors probes developed with the width and length of 0.5 inches and 0.63 inches, 0.75-inch width and 0.63-inch length, 1-inch width and 0.63-inch length, and 1-inch width and 0.89- inch length, respectively. The exposed core is about 0.08 inches each. The measurements of the sensor condition were observed based on three states as listed in Table 1.

Table 1
Condition for Sensor Measurement

State	Condition
1	the sensor is completely dry
2	the sensor is soaked into the bowl where the soil is wet
3	several minutes after the sensor is removed from the bowl and dry completely

III. RESULTS AND DISCUSSION

In this section, the change in light transmission characteristics as a function of the moisture conditions was experimentally studied. The measurements were taken considering the room temperature around 30°C. Different sensor dimensions were designed, and the effects of the sensor's width and length to the overall performance were studied.

Three different sensors were designed with three different sensor widths, while the length of the sensor was kept to 0.63 inches. The graph in Figure 5 represents the sensor with 0.5-inch width and 0.63-inch length, where the points labelled by number 1 to 3 indicate the points where the data for the three conditions were taken.

Estimation of the moisture under dry, wet conditions and after leaving to dry for several minutes, considering a linear response for the sensor's output to moisture, are listed in Table 2. From the output sensor in Figure 5, the result is converted to the voltage form and was evaluated.

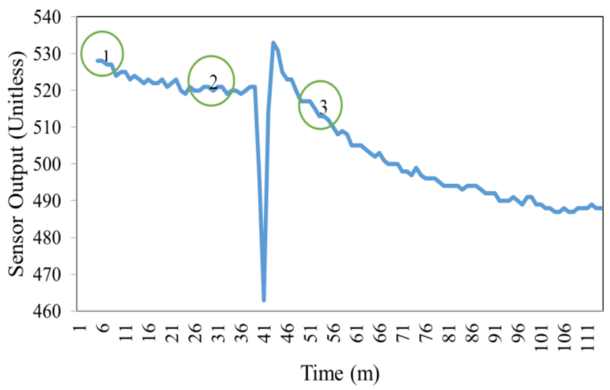

Figure 5: Graph of sensor output vs time of the data taken

Table 2
Sensor Voltage for Different Sensor Widths

Sensor	Sensor Width (inch)	Condition	Sensor Output	Voltage (V)
A	0.50	1	530	2.50
		2	488	2.39
		3	488	2.39
B	0.75	1	534	2.61
		2	599	2.93
		3	659	3.22
C	1.0	1	726	3.33
		2	733	3.59
		3	715	3.28

Based on Table 2, sensor A shows that when the sensor was completely dry, the voltage observed was 2.5V. The sensor was then soaked in the bowl for 1-2 minutes. After it was thoroughly wet, the observed voltage was 2.39V. After that, the sensor was removed from the bowl and allowed to dry. After several minutes, it can be seen that the voltage remains the same.

For sensor B, it shows that the voltage for a completely dry sensor is 2.61V. When it is saturated, the voltage is 2.93V. After leaving to dry for several minutes, the voltage is 3.22V. As for sensor C, the reading of voltage was increased when the probe was immersed in a bowl with wet soil and reduced when the sensor was removed. It is in agreement with the theory that the sensor value will increase when wet and decrease when dry. It can be concluded that, as the width of the sensor is set larger, the output reading will also increase. However, regarding stability, sensor C will be selected due to reliable reading.

To analyse the effect of the sensor's length to the sensor's performance, two different sensor lengths were tested, both with 1-inch width.

Table 3
Sensor Voltage for Different Sensor Lengths

Sensor	Sensor Length (inch)	Condition	Sensor value	Voltage (V)
C	0.63	1	726	3.33
		2	733	3.59
		3	715	3.28
D	0.87	1	859	4.20
		2	867	4.24
		3	855	4.18

Based on Table 3, it can be noted that the voltage was increased as the sensor length became longer. However, both showed the same trend where the voltage was higher when it was wet. It can be observed that from condition 1 to condition 2, both sensors values were increased and from condition 2 to condition 3, the sensor values were decreased. Based on the theory, wet sensor increases the voltage value, while dry sensor decreases the voltage value. Since the experimental observations are consistent with the theory, both sensor C and D are suggested due to the reliable reading.

IV. Conclusion

Plastic optical fibres are proven to be the critical element for developing very low-cost sensors for various applications. By adopting a simple technique, such as removing the fibre cladding, POF can react with the surrounding substance and successfully work as a sensor. This paper examines the feasibility of constructing a soil moisture sensor system to detect moisture using affordable plastic optical fibres. It is shown that sensor C with the dimension of 1-inch width, and 0.63-inch length and sensor D with the dimension of 1 inch and 0.87-inch length have the potential to be exploited as the soil moisture sensor due to its reliability. However, there is still room for improvement, where plenty of potential research can be explored. Further work includes improving the sensor performance in terms of accuracy and sensitivity. Temperature measurements can be involved, and optimisation of the sensor design can be statistically studied to develop a high-performance POF based sensor.

Acknowledgement

Our thanks to Universiti Teknikal Malaysia Melaka (UTeM) and Ministry of Higher Educations (MOHE) for the support. This research work is supported by funding from MOHE with the grant no: RACE/F3/TK2/FKEKK/F00298.

References

[1] Bilro, N. Alberto, J. L. Pinto, R. Nogueira, "Optical Sensors Based on Plastic Fibers," in *Sensors*, vol. 12, pp. 12184-12207, 2012.
[2] M. Ishtaiwi, S. Grassini, M. Parvis, A. Vallan, G. Saviano, "Nano-textured POF Surfaces to Enhance the Sensitivity of Low Concentration HF Sensors," in *Procedia Engineering*, pp. 248 – 251, 2014.
[3] K. Bremer, M. Wollweber, F. Weigand, M. Rahlves, M. Kuhne, R. Helbig,B. Roth, "Fibre optic sensors for the structural health monitoring of building Structures," in *Procedia Technology*, vol. 26, pp. 524 – 529, 2016.
[4] I. García, J. Zubia, G. Durana, G. Aldabaldetreku, M. A. Illarramendi, J. Villatoro, "Optical Fiber Sensors for Aircraft Structural Health *Monitoring," in Sensors (Basel)*, 15 (7), pp. 15494–15519, 2015.
[5] D. Jayasuriya, B. Wilson, D. Furniss, Z. Tang, E. Barney, T. M. Benson, A. B. Seddon, "Towards mid-infrared fiber-optic devices and systems for sensing, mapping and imaging," in *SPIE Proceedings*, vol. 9702, 2016.
[6] S. Laskar, S. Mukherjee, "Optical Sensing Methods for Assessment of Soil Macronutrients and other Properties for Application in Precision Agriculture: A review," in *AJET*, Vol. 4(1), pp. 2348-7305, 2016.
[7] Marco Leone, S. Principe, M. Consales, R. Parente, A. Laudati, S. Caliro, A. Cutolo, A. Cusano, "Fiber Optic Thermo-Hygrometers for Soil Moisture Monitoring," in *Sensors*, vol.17, pp.1451, 2017.
[8] J. S. Hallett ; M. Partridge ; S. W. James ; D. Tiwari ; T. Farewell, et al.,"Soil moisture content measurement using optical fiber long period gratings", in *Proc. SPIE*, vol. 10323, 25th International Conference on Optical Fiber Sensors, 103232J, doi:10.1117/12.2263427
[9] C. Schunk, B. Ruth, M. Leuchner, C. Wastl, A. Menzel, "Comparison of different methods for the in situ measurement of forest litter moisture content," in *Nat. Hazards Earth Syst. Sci.*, vol.16, pp.403–415, 2016.
[10] P. Aravind, M. Gurav, A. Mehta, R.Shelar, J. John, V. S Palaparthy, et. al., "A Wireless Multi-Sensor System For Soil Moisture Measurement," in 2015 IEEE Sensors, USA, 2015.
[11] A.A. Nadia, H. Hazura, A.R. Hanim, "The Potential of Silicon Photonic

Devices based on Micro-Ring Resonator," in *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, vol. 7(1), pp. 17-20, 2015.

[12] G. S. Kulkarn, W. Zang, Z. Zhong, "Nanoelectronic Heterodyne Sensor: A New Electronic Sensing Paradigm," in *Acc. Chem. Res.*, 49 (11), pp 2578–2586, 2016.

[13] G.Melone, P.Miodushevsky, , L.Rizzi, L.Vasanelli, "Miniaturized Thin Film Temperature Sensor For Wide Range of Measurements," in *2007 2nd International Workshop on Advances in Sensors and Interface*, Italy, 2007.

[14] A. Barrias, J. R. Casas, S. Villalba, "A Review of Distributed Optical Fiber Sensors for Civil Engineering Applications," in *Sensors*, vol. 16, pp. 748, 2016.

[15] S. GroBwig, M.-B. Schaller, L. Zou, O. Sezerman, R. Wlllscb, "Application of distributed Brillouin optical fiber sensor systems in geo-technical monitoring," in *the 6th Asia Pacific Optical Sensor Conference 2016*, China, 2016.

[16] H. Hazura, B. Mardiana, A.R Hanim, PS Menon, N Arsad, Zulatfyi F Mohammed Napiah, "Impact of coupled resonator geometry on silicon-on insulator wavelength filter characteristics," in *2011 IEEE Regional Symposium on Micro and Nanoelectronics (RSM) proc*, pp. 380-382, 2011.

[17] A. Gowri, V.V.R. Sai, "Development of LSPR based U-bent plastic optical fiber sensors," in *Sensors and Actuators B*, vol. 230, pp. 536–543, 2016.

[18] A.A Nadia, H. Hazura, A.R. Hanim, "The Potential of Silicon Photonic Devices based on Micro-Ring Resonator," in ournal of Telecommunication, Electronic and Computer Engineering (JTEC), vol. 7, no. 1, pp. 17-20, 2015.

[19] J. Zhao,T. Bao, T. Kundu, "Wide Range Fiber Displacement Sensor Based on Bending Loss," in *Journal of Sensors*, vol. 2016, Article ID 4201870, 5 pages, 2016. doi:10.1155/2016/4201870.

[20] K. Bhowmik, G.-D. Peng, Y. Luo, E. Ambikairajah, V. Lovric, "Etching process related changes and effects on solid-core single-mode polymer optical fiber grating," in *IEEE Photonic Journal*, vol. 8(1), pp. 2500109, 2016.

[21] A. M. Almarsi, M. J. Hagmann, M. S. Mousa "Enhanced Field Electron Emission from Dielectric Coated Highly Emissive Carbon Fibers," in *Appl Microsc*, 47(1), pp. 55-62, 2017.

[22] H. Hazura, N. Nadia Abd. Aziz, A.R. Hanim, A.S. Mohd Zain, S.K. Othman, Fauziyah Salehuddin, "MRR Filter Characterizations in WDM System for Digital Signals Transmissions," in *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, vol. 8(1), pp. 29-32, 2016.