

Studies on Sensor Networks with Fiber Optics for Agricultural Environment Monitoring

農業環境モニタリングのための光ファイバセンサネットワークの研究

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ABSTRACT

本研究は、土壌重力水を検知できるヘテロコア光ファイバSPR(Surface Plasmon Resonance)センサを用いて、従来のセンサネットワークの課題を解決する新しい農業支援センサネットワークの設計および構築を目的とする。このヘテロコア光ファイバSPRセンサはセンシングとデータ通信との融合技術を持ち、センシングのために金(Au)および五酸化タンタル (Ta_2O_5) 皮膜を使用している。農業環境をモニタリングするためには、長距離ファイバを用いたセンシングと一本のファイバを用いた多地点の計測が必要である。そこで、1kmのファイバを用いてセンシングとデータ通信が可能であることを検証した。また、一本のファイバ上で複数センサの識別を可能とするため、ネットワークの管理プロトコルとして標準化されているSNMP (Simple Network Management Protocol)を用いた。ここでは、計測したセンサの光強度の変化値をMIB (Management Information Base)に追加し、光強度によってTrapを送信するための設定を行った。これにより、複数のパターンでSPRセンサの光強度変化値を計測することで、反応しているセンサを識別することが可能であった。

Keywords: hetero-core optical fiber sensor, sensor networks remote management, agricultural environment monitoring

1. Introduction

Agriculture faces many challenges, including climate change, limited water resources, environmental pollution, aging and shortages of farm workers, and increase of greenhouse gas emissions. Climate change adds uncertainty to projections of agricultural output, highlighting the importance of monitoring and research to refine those predictions. Due to aging of the workforce and lack of replacement human resources in rural communities, an information infrastructure is needed to support agricultural activities. Ruiz-Altisent et al. [1] reviewed various sensing technologies for agriculture support, such as wireless sensor networks and radio frequency identification sensors.

Recently, optical fiber has been used not only for data communications but for sensor applications. In this study, we employ the HC spliced optical fiber surface plasmon resonance (SPR) sensor (HC-SPR sensor) that detects soil gravity water. We propose and evaluate an optical fiber sensor networks using the HC-SPR sensor to support the agricultural environment remote monitoring.

2. Research Objectives

Our objective is to propose and construct a remotely monitor fiber optic sensor system for soil gravity water monitoring in agricultural environments. The system is capable of adaptation to larger areas with real-time measurement and data transmission. In order to remote monitor a sensor networks, we study the optical sensor networks remote management using the internet-standard protocol. The study involves the installation of multipoint sensors into the same fiber line and differentiates the response from each sensor by using the internet-standard protocol – Simple Network Management Protocol (SNMP).

There is a trade-off relationship between communications quality and measuring accuracy. Therefore, balanc-

ing data communications and measurement sensitivity features requires selecting proper devices and consistently integrating them. The main contributions of this study are system integration that meets the requirements for soil gravity water monitoring in agricultural environment and to realize the remote management of fiber optic sensor networks.

3. Related Research and Remaining Issue of Previous Research

A) Current Sensor Network

Recently, wireless sensor networks (WSNs) have been extensively developed and studied. Wireless sensors are applicable in various monitoring areas[1][2][3][4] including military, medical and health, industrial, nuclear plant maintenance, ocean, agriculture, airport, disaster management, and home networking applications.

B) Natural Environment Monitoring System

A number of natural environment monitoring systems that focus on agriculture have been researched and studied. A regional on-farm wireless sensor network has been implemented in eastern Washington [5], and the NAV system has been designed for remote real-time monitoring of a vineyard in Italy [6]. Several commercial services are available in Japan, such as the Geographic Information System by Fujitsu, and Agriculture ICT Solution by NEC. FieldServer by Elab Experience [7] is a sensor network environmental monitoring device designed for camera and sensor communications.

By comparing to the sensor networks and natural environment monitoring systems mentioned in above section, some remaining issues of the existing research are summarized as follows:

(i) Larger, complex system configuration and function: Wireless sensor networks and existing commercial sys-

tems are complex and involve large system configurations.

(ii) Limited sensor's power or battery supply: Power management is a major concern in wireless sensor network systems [9] as limited battery lifetime may interrupt data communications [8].

(iii) Low reliability on data communications: Data communications reliability: Given that no wired network is present, sensors must communicate using ad hoc wireless networking [8], which cannot produce high-connectivity networks.

(iv) Higher production cost: per-unit node cost is often a predominant factor in the overall network cost. To provide a low cost sensor network, manufacturing cost of a sensor is required to be low [8]

4. System Requirements

The requirements of our proposed system are defined based on user needs and refer to the remaining issues discussed in the previous section. The system requirements are described below:

- i. Simpler configuration sensing system and network management: the number of system components such as communications and measurement devices are minimized. A simple network management method is utilized to manage the sensor network.
- ii. Continuous power supply: Being different from wireless sensors, the FOSs do not need power supply for operation, while other measuring devices are connected to the power directly. Therefore, the installation of FOSs can solve the power or battery supply issues for the sensors.
- iii. Data communications reliability and real-time measurement: the system has wired connection with continuous power supply which ensuring the data communications reliability. It is one of the most crucial features for our monitoring system to send real-time measured data to users.
- iv. Adaptable to larger area of environment: Target of the monitored areas such as a farm should cover a larger area. Thus, a system which is able to offer a soil water monitoring service in a broad area needs to be studied.
- v. Multi-point sensing: Sensors are tandemly installed in the same fiber line in order to collect data in some different points.

5. Hetero-core Optical fiber Sensor for Soil Gravity Water Monitoring (HC-SPR)

The structure of the fiber consists of a multimode transmission fiber and a single-mode fiber segment inserted in the transmission line, where the core of the multimode fiber is 50 μm and the core of the single mode fiber is 3 μm . The core diameter of the inserted fiber, which is smaller than the transmission fiber, works as a sensor portion. The sensor portion is fabricated by cylindrically coating the bare fiber surface with metal using an RF sputtering machine. In our research, the coating on the cylindrical surface of the hetero-core portion with metal material allows the formation of a surface Plasmon wave when the evanescent wave reflects on the

metal surface. The light leakage generates an evanescent wave in the course of the cladding mode development when reflecting at the boundary surface between the cladding and the surrounding medium. Thus, this device can be used as a sensor for measuring refractive index by measuring the resonance wavelength.

5.1 Tantalum Pentoxide (Ta₂O₅)-coated HC-SPR Sensor for wide-area monitoring

A Ta₂O₅ coating over part of the metallic lamina on the surface of an SPR sensor makes it possible to shift the resonant wavelength of SPR to a longer wavelength, due to the higher dielectric constant of Ta₂O₅ [10]. The SPR resonance wavelength is largely shifted to a region over 1000 nm by thickening the Ta₂O₅ coating to 60 nm. Therefore, proper adjustment of the Ta₂O₅ coating thickness can be expected to induce the SPR phenomenon even at the 1310 nm wavelength used for long-distance data communications.

This section describes an experiment for verification of short- and long-distance data communications and sensing using a Ta₂O₅-coated HC-SPR sensor, and the results of that experiment.

Experiments has been conducted to verify the data communications and sensing characteristics of an HC-SPR sensor coated with 25 nm of Au and 60 nm of Ta₂O₅ in a wide area of 1000 m. Figure 1 shows the experimental setup. The experimental environment was constructed using two 500 m rolls of 50 μm core multimode fiber. A multimode optical coupler was used as a signal splitter. A power meter was used to measure the light loss. In this study, pure water was used as the test liquid.

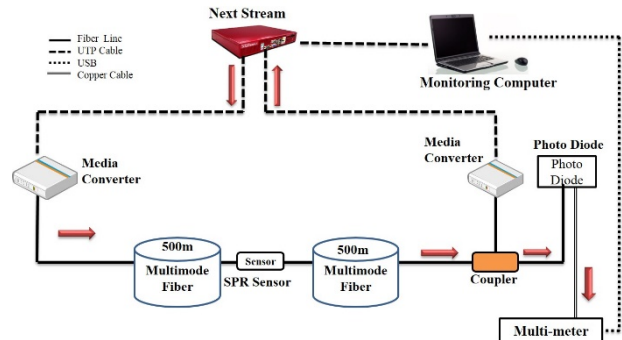


Fig 1. Experimental setup to verify the data communications and sensing of an Au and Ta₂O₅ HC-SPR sensor over a long distance

At the early stage of the experiment, we face difficulties to capture expected results. After some details troubleshooting, we come to realize that the media converter and photodiode's power need to be reset each time a new configuration is set. The power of these devices needs to be reset, in order to tune the baseline of each configuration

Figure 2 shows the experimental results for the 1000 m model. In the first 30 s, the light loss was zero while the sensor was in air. From 31 to 60 s and from 90 to 120 s the sensor was immersed in water. The average power loss when the sensor was immersed in water was 0.6 dB. The NextStream detected no FCS errors and data communications were not interrupted. The result demonstrates that our proposed system can perform sensing and data

communications without interruption while successfully measuring power loss, even at a distance of 1000 m.

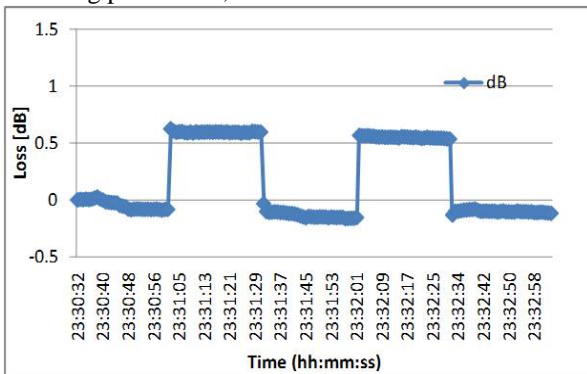


Fig 2. Experimental results of verifying the data communications and sensing characteristics of a Ta₂O₅-coated HC-SPR sensor at a distance of 1000 m.

5.2 System Hardware Configuration

Figure 3 shows the construction of the proposed system. The system hardware configuration consists of a hetero-core spliced SPR sensor, media converter (Core System Japan Co., Ltd.), Ethernet switch, coupler, photodiode, the USB device server, power meter, and a notebook PC.

During the test, the web camera which connected via the USB device server has difficulties to be recognized and connection was not stable. After troubleshooting, we found that the issue was caused by the light power differences of both media converter. By replacing one of the media converters, the issue was overcome and connection is stable.

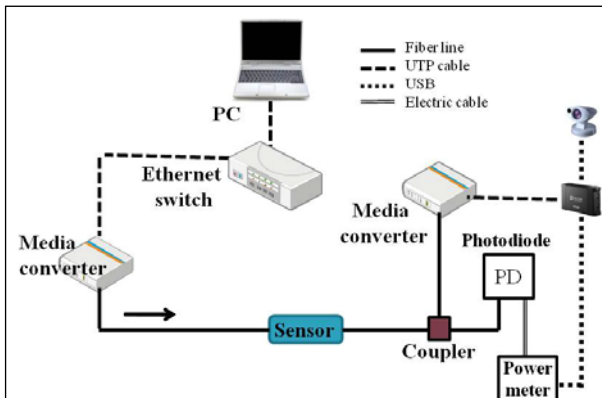


Fig 3. Proposed system configuration of HC-SPR sensor system for agricultural environment monitoring

5.3 Field Trial for Soil Gravity Water Monitoring in an Agricultural Environment

Based on the conceptual system configuration (Figure 3), we constructed an HC-SPR sensor system for soil gravity water monitoring in agricultural environments, and conducted an experiment to evaluate performance of the system. We used an HC-SPR sensor coated with 25 nm of Au and 60 nm of Ta₂O₅.

Andosol was used after drying to 15–20% water content over about 24 h in a dryer. Next, the sensor was installed in a plastic chassis sensor unit (W: 55 mm × H: 28 mm × D: 95 mm). The top of the case was covered with an urethane mesh to prevent soil from dropping directly into the sensor case. Next, the sensor unit was set 5 cm below

the top of the Andosol (Figure 4).

The experiment started by spraying 1000 ml water via a sprinkler as uniformly as possible on the surface of the Andosol within 60 s.

The position of the sensor in the casing and in the soil have affect toward the results output. A few experiments have been carried on by adjusting the position of the sensor in the casing and in the soil until the expected results have successfully obtained.

Figure 5 shows the results of this experiment. The watering process started at 13:10:00, and took about 60 s to complete. A power meter was used to measure the sensing data, and the baseline of light loss for this experiment was zero. Initially, the Andosol moisture level was less than 20%. The dry soil absorbed the sprayed water instantly, and thus the sensor could not detect the water immediately after the watering process started. Detection started after about 30s of watering. The power loss gradually increased to 1.5 dB. After the watering process stopped, the power loss from the sensor maintained at 1.5 dB as long the soil was kept moist. In addition, during the experiment, video data were seamlessly captured. The experimental result shows that data communications and sensing was successfully carried out with an HC-SPR sensor set in Andosol.

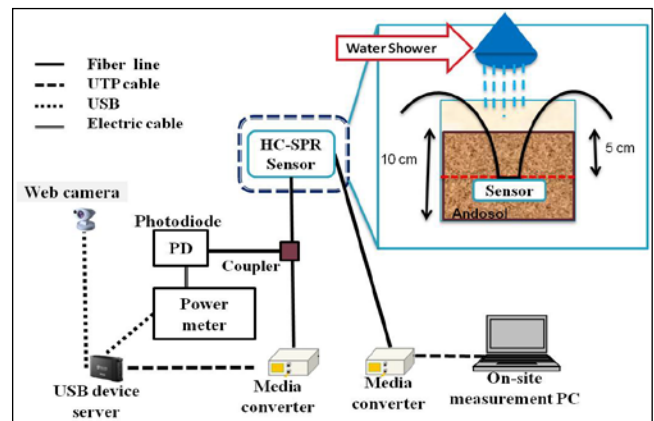


Fig 4. Image of the system performance evaluation with HC-SPR sensor under the Andosol

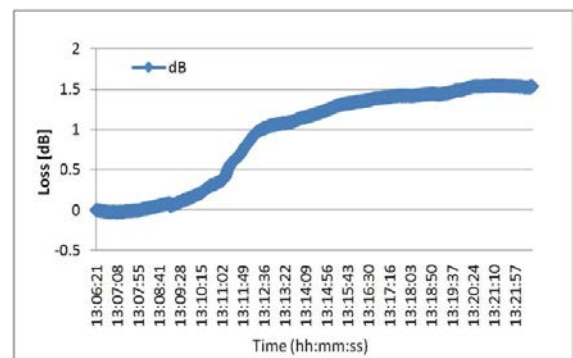


Fig 5. Experimental results for an HC-SPR sensor set in Andosol.

6. Remote Management of Optical Sensor Networks (OSN) with the Internet-based Protocol – SNMP

In a sensor networks, multiple sensors are involves in the sensing. In order to construct a remote monitor optical sensor networks, a method to identify and differentiate the multiple optical fiber sensors that install in the same fiber line is needed. Therefore, we propose a remote

management for optical sensor networks with the Internet-based Protocol – SNMP (Simple Network Management Protocol).

The standard internet-based protocol SNMP can detect the changes in the network environment by setting a threshold value. By defining the MIB (Management Information Base) that is uniquely owned by a SNMP agent and setting the threshold value, the operational status of the multiple sensors can be identified and the value can be stored.

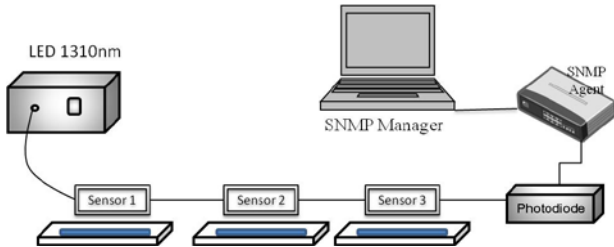


Fig. 6 System configuration of OSN remote management using the SNMP for SPR sensor

Figure 6 shows the system configuration of the OSN remote management. Three HC-SPR sensors with different insertion length are used. The insertion length of sensor 1 is 2mm, sensor 2 is 5mm and sensor 3 is 15mm. The system devices are LED light source, photodiode, SPR sensors, SNMP agent and SNMP Manager.

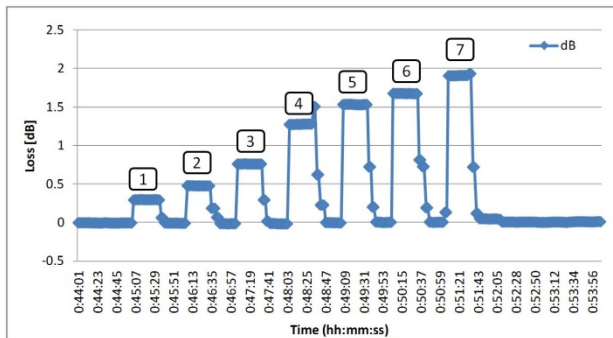


Fig.7 The sensors loss value measure using SNMP.

TABLE I. TRAP NUMBER ASSIGNMENT FOR SPR SENSOR AND DETECTION RESULTS

No	Test Pattern Description	Assigned Trap Number	Result
1	Sensor 1 ON	Trap No 22	Detected
2	Sensor 2 ON	Trap No 23	Detected
3	Sensor 1,2 ON	Trap No 24	Detected
4	Sensor 3 ON	Trap No 25	Detected
5	Sensor 1,3 ON	Trap No 26	Detected
6	Sensor 2,3 ON	Trap No 27	Detected
7	Sensor 1,2,3 ON	Trap No 28	Detected

The experiment has been carried on with the test patterns listed in table I, which ‘ON’ means the sensor is immersed in the water. The loss value of the sensors when immersed into the water is captured using the SNMP agent and the value is calculated. The results are shown in figure 7.

The results confirmed that each combination patterns can detect a different loss value. Therefore, we use this value to set the threshold value in the SNMP agent and

make configuration of the MIB settings. Each combination patterns are assigned to a TRAP number in SNMP manager. When the sensor(s) is immersed into water, the TRAP numbers will be shown according to the respond of the sensor(s). Table I shows the result of the experiment. All test patterns are successfully been detected.

7. Conclusion and Future Works

We described and analyzed a hetero-core spliced optical fiber SPR sensor system for soil monitoring of agricultural environments. We achieved our goal by design and construct a remote monitored sensor system with a simpler configuration that provides real-time agricultural environmental monitoring to target users. Furthermore, the distance of data transmission for large-area monitoring has been realized by utilized an HC-SPR sensor coated with Ta2O5 and adopted a wavelength of 1310 nm. The HC-SPR sensor network system has been constructed, and experiments succeeded in gathering real-time sensor data from the system.

On the other hand, to differentiate the response of the sensors which tandem installed in the same fiber line, we have proposed a remote management of sensor networks with the Internet-based Protocol – SNMP. The responds from each sensor and their combinations successfully been identified.

Our future works have issues on developing the system integration of data communications and sensing functions simultaneously with multiple sensing points even in a multimode fiber line.

Reference

- [1] Ruiz-Altisent, M., Ruiz-Garcia, L., Moreda, G.P., Renfu Lu, Hernandez-Sanchez, N., Correa, E.C., Diezma, B., Nicolai, B., Garcia-Ramos, J., 2010. Sensors for product characterization and quality of specialty crops—A review. Computers and Electronics in Agriculture, Vol. 74, Issue 2, November 2010, pp 176-194.
- [2] Rahman, K. C., (2010). A survey on Sensor Network. Journal of Computer and Information Technology, Vol. 1 (2010), pp. 76-87.
- [3] Corke, P., Wark, T., Jurdak, R., Hu, W., Vaencia, P., Moore, D., 2010. Environmental Wireless Sensor Network. Proceedings of the IEEE, Vol.98, No.11, November 2010.
- [4] Hill J.L., and Culler, D.E., 2002. Mica: a wireless platform for deeply embedded network. IEEE Micro, vol.22, no.6, pp.12-24.
- [5] Pierce, F.J., Elliott, T.V., 2008. Regional and on-farm wireless sensor networks for agricultural systems in Eastern Washington. Computers and Electronics in Agriculture, Vol. 61, Issue 1, April 2008, pp. 32-43.
- [6] Matese, A., Di Gennaro, S.F., Zaldei, A., Genesisio, L., Vaccari, F.P., 2009. A wireless sensor network for precision viticulture: The NAV system. Computers and Electronics in Agriculture, Volume 69, Issue 1, November 2009, pp. 51-58.
- [7] Elab experience, FieldServer, 2010. <http://www.elab-experience.com/>
- [8] Tanenbaum, A.S., Gamage, C., Crispo, B., 2006. Taking Sensor Networks from the Lab to the Jungle. Computer, Aug. 2006., Vol.39, no.8, pp.98-100.
- [9] Burrell, J., Brooke, T., Beckwith, R., 2004. Vineyard computing: sensor networks in agricultural production, Pervasive Computing, IEEE, vol.3, no.1, pp. 38- 45.
- [10] Slavik, R., Homola, J., Ctyroky, J., Brynda, E., 2001. Novel spectral fiber optic sensor based on surface plasmon resonance. Sensors and Actuators B: Chemical, Volume 74, Issues 1-3, Proceedings of the 5th European Conference on Optical Chemical Sensors and Biosensors, 15 April 2001, pp. 106-111.