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A. Padhye, E. Anthoulakis, S. Christodoulou, M. N. Zervas, M. Konstantaki, S. Pissadakis, "Optical fiber sensors for detecting spraying drift in drone agricultural applications," Proc. SPIE 11953, Optical Fibers and Sensors for Medical Diagnostics, Treatment and Environmental Applications XXII, 119530H (2 March 2022); doi: 10.1117/12.2609294

SPIE.

Event: SPIE BiOS, 2022, San Francisco, California, United States

Optical fiber sensors for detecting spraying drift in drone agricultural applications

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ABSTRACT

Chemical pesticides/ fertilizer drone spraying is becoming increasingly available aiming to optimize farming processes and enhance agricultural production. One of the main considerations that currently limits widespan endorsement of the approach is the undesirable drift of the spraying cloud outside the targeted area. Herein, we propose the use of optical fiber long period gratings of extended length (~9 cm) as line sensors for tracing sprayed copper chlorophyllin water droplet distribution. Preliminary results indicate a correlation between particle density and LPG wavelength and strength change. Indicatively, for a coverage of 3.9 particles /mm^2 the corresponding LPG wavelength and strength change is 65 pm and 1.3 dB, respectively. Following full calibration in laboratory environment, sensors will be deployed in the field during a drone spraying operation for sensor evaluation under actual conditions.

Keywords: optical fiber sensors, agricultural applications, drone spraying, optical fiber long period gratings, droplet distribution

1. INTRODUCTION

Drones or Unmanned Aircraft Systems (UAS) are transforming agricultural practices aiming to increase efficiency in certain aspects of the farming process [1]. Crop monitoring, chemical pesticides/ fertilizer spraying and keeping track of livestock are just a few examples of how drone technology is being employed by the modern farming industry. Drone spraying [2], in particular, is becoming increasingly popular due to its distinctive advantages such as autonomy, fast operation and water/ pesticide volume reduction compared to traditional land spraying methods. One of the considerations that currently limits widespan endorsement of this technique is the undesirable drift of the spraying cloud to areas outside the targeted zone. Typical methods for measuring droplet drift during drone spraying are based either on the deployment of water sensitive papers, that however lack accuracy, or costly dummy androids dressed with hydrophilic uniforms [3].

Optical fiber sensors have been incorporated in a number of agricultural applications in the last decade and constitute important new tools in areas such as optimized irrigation and use of pesticides, soil assessment and machinery performance. Their distinctive advantages such as remote operation, electromagnetic immunity and miniature dimensions establish optical fiber sensors as strong assets in precision farming [4]. Herein, we propose the use of optical fiber long period gratings (LPGs) of extended length (~9 cm) as line sensors for tracing drone spraying droplet distribution. Deposition of spayed droplets on the surface of the LPG [5] will alter the strength and/or wavelength of the LPG attenuation bands and, following calibration, it can be used to estimate droplet density at the location of the sensor. By positioning a number of sensors at distinct distances from the spraying nozzles and comparing LPG spectra, before and after the spraying operation, we can estimate not only the boundaries of the affected area but also the density of coverage at specific locations.

For the development of the sensor, long period gratings were fabricated using the point-by-point inscription method and were initially tested in laboratory environment. Green colored dye solution derived from sodium copper chlorophyllin in water with variable concentration was sprayed, using an airbrush, on the LPG to determine the response of the sensor and

Optical Fibers and Sensors for Medical Diagnostics, Treatment and Environmental Applications XXII
edited by Israel Gannot, Katy Roodenko, Proc. of SPIE Vol. 11953, 119530H

identify optimum solution concentration. Furthermore, the spaying distance was varied to determine the range of operation of the system under the aforementioned conditions. For all experiments water sensitive paper samples were used, along the optical fiber sensor, to quantify the droplet density around the grating region and provide reference for calibration. Following full calibration in laboratory environment, up to 10 sensors will be deployed in the field, during an actual drone spraying operation, to trace spatial droplet density and monitor spraying drift.

2. EXPERIMENTAL

Long period gratings were inscribed in Boron co-doped germanosilicate fiber (PS1250/1500–Fibercore Ltd) using the point-by-point fabrication technique that offers high flexibility for tailored grating parameters. The beam of a 248 nm, 10 ns, high coherence TUI BraggStar KrF excimer laser [6] was focused down to 203 μm, half the period of LPG, using a cylindrical lens. For grating inscription, the optical fiber was positioned on a motorized stage and was axially translated by 1 period interval (407 μm) at the location of the focused laser beam resulting in a periodic exposure of the fiber. The inscription process was monitored on line by launching light from a broadband near-IR superluminescent diode into the fiber and monitoring the output with an optical spectrum analyzer (OSA). The inscription beam had a 210 mJ/cm^2 pulse fluence while each half period was irradiated by 50 pulses, at a repetition rate of 125 Hz. The inscribed LPGs had a 9 cm length with a strong, 18 dB, attenuation band observable in the 1470-1510 nm region as illustrated in Figure 1.

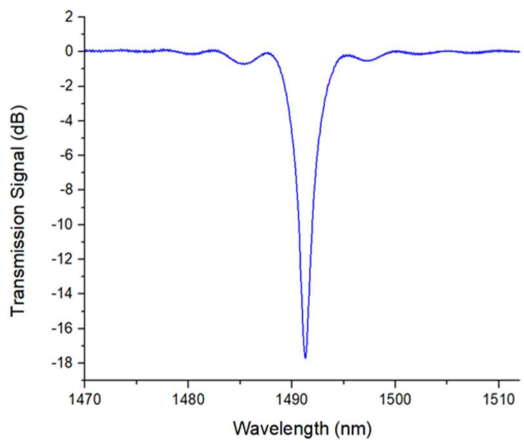

Figure 1. Attenuation band of a typical 9 cm Long Period Grating inscribed by the point-by-point technique.

To test the response of the sensors, spraying operations were initially carried out in the laboratory using an airbrush. The experimental arrangement is illustrated in the upper part of Figure 2. The sensor was placed on a table surface while the airbrush was positioned at an elevated height. Green colored dye derived from sodium copper chlorophyllin (GreenHerb Biological Technology Co., Ltd) was dissolved in water and was used for all spraying sessions with 10-30 mg/ml concentration range. For the calibration of the sensor, the airbrush nozzle - LPG separation was varied and spraying was performed for four different distances starting from 2 m down to 0.5 m with decrement of 0.5 m. The average spraying duration was set at 20s followed by 20s resting interval for each spraying session and then the optical spectrum of the LPG was recorded. For all measurements, a lateral offset of 14 cm was maintained between the centre of LPG and the airbrush nozzle as shown in the lower part Figure 2. This lateral offset resembles on field environment where the drone might not always be in line with the LPG. A pair of water sensitive paper samples (20 mm x 26 mm) was placed beside the LPG to quantify sprayed droplet density. One paper was kept stationary throughout all rounds of spraying while the second was replaced after each round. To correlate number of droplets with spectral data, photographs of water sensitive paper samples were obtained using a standard 12MP smartphone camera at 5x digital zoom and under identical light exposure conditions while ImageJ software was used to estimate the number of particles per mm^2.

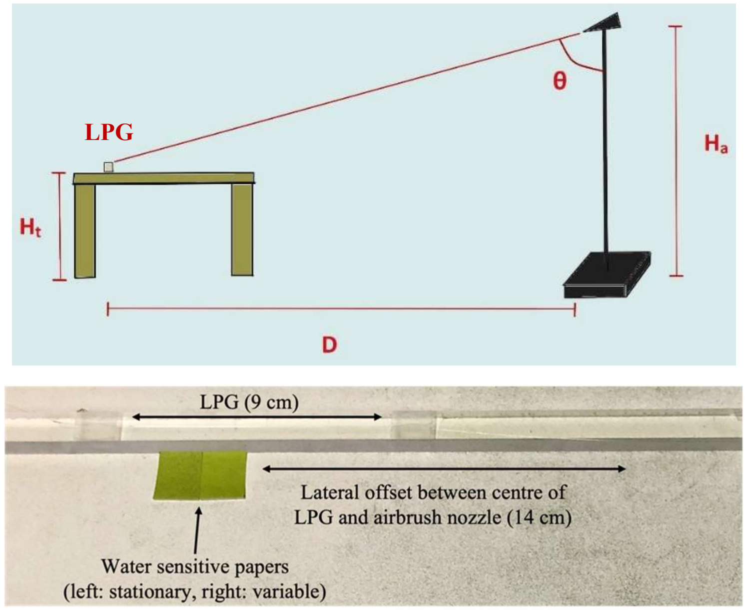

Figure 2. (upper) Experimental arrangement for spraying operation H_t=0.75m, H_a=1.5m, D =0.5-2m, (lower) LPG sensor and water sensitive paper positioning.

3. RESULTS AND DISCUSSION

Figure 3 (left) illustrates the spectra for 2 consecutive sprayings using a 30 mg/ml solution with a separation (D) of 1 m between the sensor and airbrush nozzle position. The corresponding images of water sensitive papers for each round are also illustrated in the figure with an indication of the calculated number of particles per mm^2. Similar recording and analysis was carried out for different distances and also experiments were repeated for a solution of 10 mg/ml concentration.

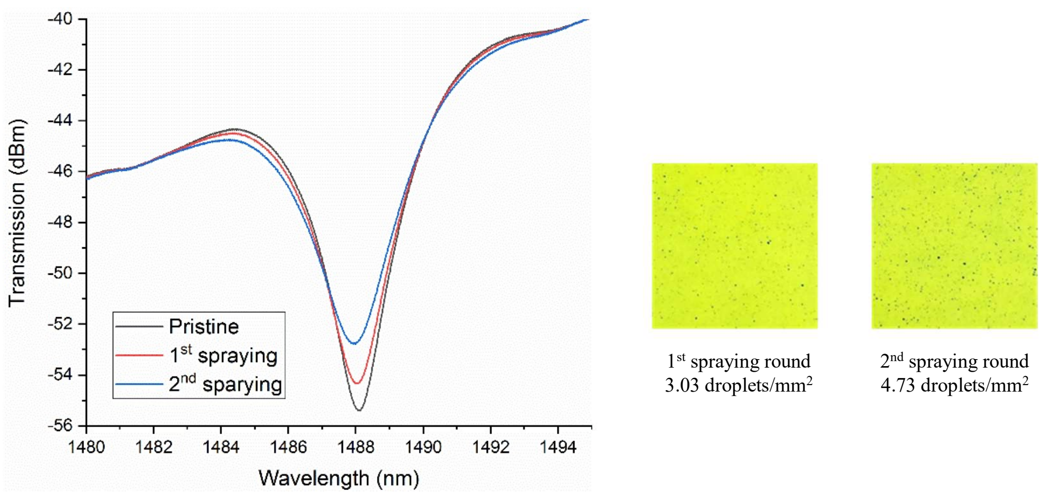

Figure 3. (left) Change in LPG transmission spectra for sprayings at 1 m separation between sensor and nozzle for a 30 mg/ml solution (right) corresponding droplet density on water sensitive paper.

Following the aforementioned experiments, the variation in strength (ΔT) and wavelength (Δλ) of the LPG attenuation band was calculated and is illustrated in Figure 4 as a function of corresponding average particles/mm^2 for both dye concentrations of 30 mg/ml and 10 mg/ml. A clear correlation between both ΔT and Δλ and particle density is evident. Specifically, for the 30 mg/ml solution, for a coverage of 3.9 particles /mm^2 the corresponding LPG wavelength and strength change is 65 pm and 1.3 dB, respectively. For the solution of lower concentration (10 mg/ml) as expected, higher particle densities are required to induce a measurable alteration in the strength and wavelength of the LPG however changes are recorded and lower solvent concentrations may be favorable in applications with wide coverage.

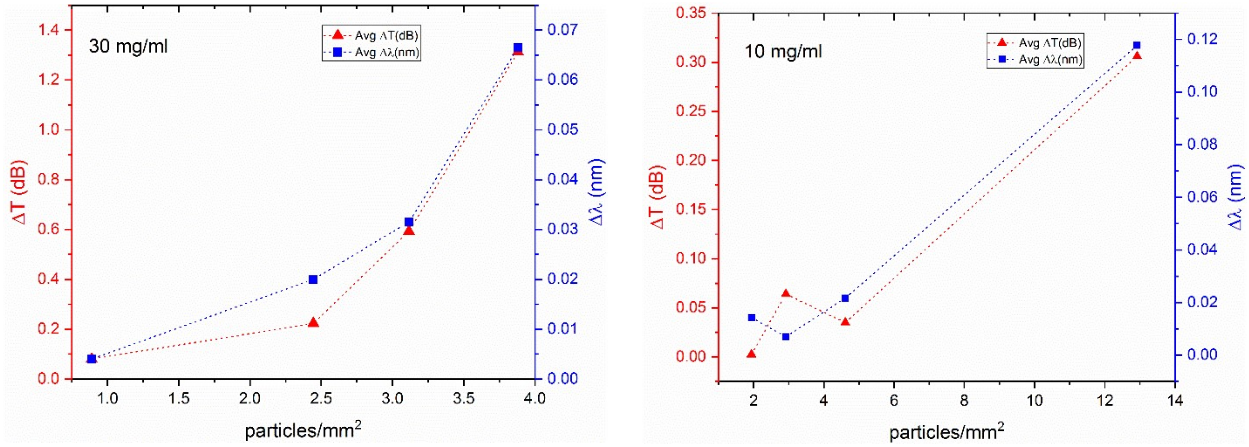

Figure 4. Variation in strength and wavelength of LPG attenuation band versus average particle density for (left) 30mg/ml and (right) 10 mg/ml sodium copper chlorophyllin water solutions.

4. CONCLUSIONS

We present preliminary laboratory results towards the development of an optical fiber long period grating sensor for detecting spraying drift in drone agricultural applications. Optical fiber long period gratings of extended length (~9 cm) fabricated by the point-by-point technique record a 1.3 dB variation in strength and a 65 pm change in central wavelength of the LPG attenuation band under optimum sprayed solution concentration and spraying distance but at lateral offset resembling on field environment. The manifold enhanced sensitivity over shorter length LPGs is attributed to the large detection area (~11 mm^2) available for the ~9 cm long grating with 0.125 mm cladding diameter. These results confirm the usability of LPGs for droplet detection to measure drift effects during drone spraying operation. LPGs detection capability could be further enhanced following specialty surface functionalisation of the fiber to increase its hydrophilicity and droplet attachment efficiency onto silica. Sensor deployment in the field, during a drone spraying operation, is currently underway to evaluate its performance under actual conditions.

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