A Sparking Innovation: High Spatial Resolution Liquid Level Sensor Using a Side Illuminated Optical Fiber

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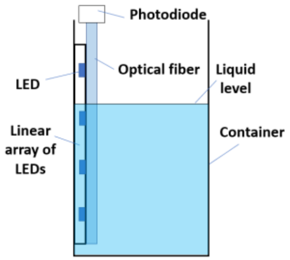
Introduction

Light is a wave made of vibrating Electric and Magnetic fields. Light can reflect and refract when incident at the interface of two media of different optical densities, or index of refraction, such as air, water, plastic, glass and others. These properties can be used in several applications. In this presentation, we describe a side illuminated optical fiber sensor that uses the refractive indices of air, water and plastic to determine the liquid level along the fiber length. When we illuminate the cylindrical surface of an optical fiber, the so-called side illumination, a considerable amount of light can be carried by the fiber. We found that by changing the refractive index of the medium surrounding the fiber, from air to water, we get a drastic change in the signal: from 70% to 100%. Using this effect, we tested an inexpensive optical fiber liquid leve sensor with a potential resolution of 3 microns. Back of the envelope calculations also predicts an average resolution of 3 x 10^{-4} units in index of refraction.

Side Illumination of an Optical Fiber

CONFIGURATION

The Figure on the right illustrates the configuration of our sensor. The optical fiber is side illuminated by an LED which injects light into the fiber. A photodiode then measures the light intensity at the fiber tip. This intensity is a function of the refractive index surrounding the fiber: when the liquid level is below/above the LED, the intensity is high/low.



MATERIALS

In our preliminary experiments we used the following:

- Sensor: a 15 cm long plastic optical fiber.
- Light source: a circuit board with a linear array of ten Light Emitting Diodes, LEDs, 2 mm x 2 mm each, separated by 1 cm.
- Detection system: an intensity to frequency converter photodiode.
- Container: an one-liter graduated cylinder, inner diameter 5.00 cm.
- A scale with 0.01 g resolution and
- A pump to remove and add water from/to the graduated cylinder.

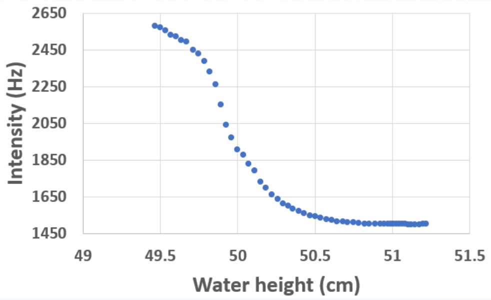
PROCEDURE

- We mounted the optical fiber on the top of the linear array of LEDs.
- We placed the tip of the fiber in front of the photodiode to measure the light intensity guided by the fiber.
- We fixed the optical fiber, the linear array of LEDs and the photodiode set to the inner wall of the graduated cylinder using wing nuts and bolts.
- We placed the graduated cylinder/optical fiber sensor set on the top of a scale and tared it.
- We filled the graduated cylinder with water until the top LED was completely covered.
- Measured the mass of the water.
- Turned on the first LED and measured the intensity, in Hz, produced by this source.
- Removed 0.37 to 0.77 g of water using the pump: by removing and adding water to the container, we could control the liquid level by amounts that varied between 0.16 to 0.4 mm.
- Repeated steps 6, 7 and 8 several times until the water level was below the first LED.

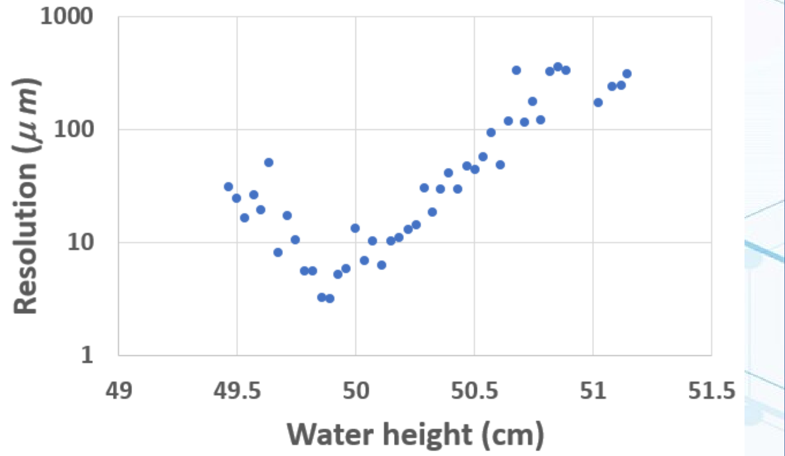
Data Analysis

All this raw data, mass of the water and light intensity, was logged into an Excel spreadsheet. Then, we processed and analyzed the data. We:

- Used the mass of water and the inner diameter of the cylinder to determine the liquid level, *h*, inside the cylinder.
- Plotted the light intensity *I* versus the liquid level *h*: the result is the one displayed in the second graph.



- Determined the change in signal, ΔI, and the change in height, Δh.
- Determined the sensitivity of the sensor, $\Delta I/\Delta h$ and
- Determined the potential resolution of the sensor, *R*, in microns, by taking the inverse of the sensitivity, and plotted it in a log scale (last graph). The resolution is a function of the height of the water column and reaches a maximum of 3 microns at h=49.9 cm.



Application and Uses

We are investigating several applications of this sensor:

- Keeping track of the oil level during oil mining.
- Activating an electric command based on a varying liquid level. For example, the device can be programmed to send a signal when a tank is empty.
- As a sensor to determine liquid level in hydroponic facilities, fuel tanks and others.

Conclusions

We demonstrated a very simple and inexpensive optical fiber liquid sensor that uses side illumination and has a potential resolution of 3 microns: such a micrometric resolution is surprising in view of the simple configuration of this device. Improvements to this sensor can be achieved by using higher intensity LEDs, optical fibers of higher guiding efficiency and more stable electronics.

The background picture is a product of Starline on freepik.com. In addition, the application image is a product of portlets.arcticportals.org.

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