

Fiber optic grating moisture and humidity sensors

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ABSTRACT

Blue Road Research is developing moisture-sensing technology that is capable of precision measurements of relative humidity and soil moisture content. Based on optical fiber sensor technology, the sensors are highly corrosion and EMI resistant and can be installed in locations where it would be impractical to insert a bulky conventional sensor. While the sensors are currently in the research and development phase, Blue Road Research has demonstrated the performance of the technology and is moving toward a commercially available product.

Keywords: Moisture, relative humidity, temperature, grating, sensor

1. INTRODUCTION

The two current areas of focus for the moisture sensing technology are relative humidity and soil moisture content. Several configurations of sensors have been developed in order to accurately measure moisture in these areas. Relative humidity sensors have been tested independently and multiplexed with temperature sensors. A combination temperature-relative humidity sensor is presented here. Also, numerous configurations of sensors have been developed for the purpose of detecting soil moisture content. The most recent prototype is presented here along with a brief summary of field tests conducted with an earlier version.

The temperature – relative humidity (RH) probe is shown in figure 1. Figure 2 is a close-up of the probe and shows the holes over the relative humidity portion of the sensor. There is a single fiber in the tube that has two Bragg gratings written into the fiber. One of the Bragg gratings responds to temperature only and the other Bragg grating responds to both temperature and relative humidity. The central wavelengths of the gratings are separated by two nanometers. Once temperature effects are backed out of the data that contains both temperature and relative humidity, the relative humidity can be obtained. The stainless steel housing has an outside diameter 3 mm, an inside diameter of 1.75 mm, and is approximately 15 cm long.



Figure 1: The probe for measuring temperature and relative humidity



Figure 2: The holes are over the relative humidity grating

The soil moisture sensor is shown in Figure 3. This sensor includes a hydrophilic medium encased in a water permeable housing. When in the presence of water, the sensor gives a dramatic response. The prototype shown here is constructed of stainless steel, aluminum and brass components. As the product is moved toward a commercial market, the housing will be constructed of a more corrosion resistant material.



Figure 3: Side and end views of the moisture sensor housing

Several series of test were conducted with each of these sensors using Blue Road Research's calibration and test station.

2. CALIBRATION AND TEST STATION

The calibration and test station is shown in Figure 4. The environmental chamber is on the left and the light source, wavemeter, optical switch and computer are in the rack mount cabinet. The computer has a programmable LabView® program that controls the environmental chamber and collects the temperature, relative humidity and wavelength data. The temperature and relative humidity data is captured from instruments that have NIST traceable calibrations.



Figure 4: Calibration and testing station

The performance of the environmental chamber for ramping relative humidity at 25 °C is shown in Figure 5. Statistics for relative humidity in the environmental chamber are shown in Table 1. Note that a sample size of 100 appears to give good results. While the relative humidity is ramped the temperature is held constant. The descriptive statistics for temperature during ramping the relative humidity are in Table 2.

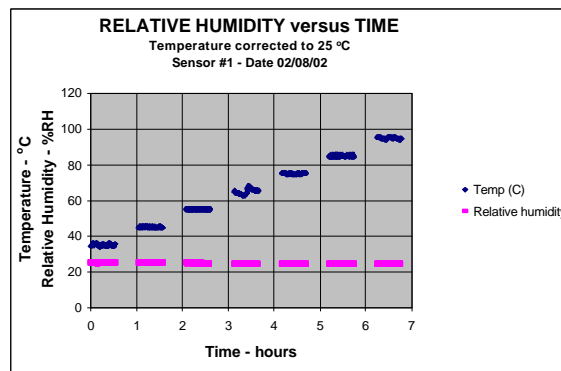


Figure 5: Relative humidity ramped

Table 1: Statistics for relative humidity

RELATIVE HUMIDITY				
Sensor #1 - 02/08/02				
Set Point °C	Relative Humidity %RH	Standard Deviation	Sample Size	Confidence Level @ 95%
35.0	35	0.55	100	0.108
45.0	45	0.14	100	0.027
55.0	55	0.09	100	0.017
65.0	65	1.47	100	0.289
75.0	75	0.23	100	0.044
85.00	85	0.37	100	0.072
95.00	95	0.31	100	0.060

Table 2: Statistics for temperature

TEMPERATURE	
Sensor #1 - 02/08/02	
Set Point	25.0
Mean	25.0
Standard Error	0.016
Standard Deviation	0.431
Range	0.61
Minimum	24.71
Maximum	25.32
Count	700
Confidence Level(95.0%)	0.032

The performance of the environmental chamber for ramping temperature at 50% relative humidity is shown in the figure below. Statistics for temperature in the environmental chamber are shown in Table 3. Note that a sample size of 25 has good precision and accuracy. While the temperature is ramped the relative humidity is held constant. The descriptive statistics for relative humidity during ramping the temperature are in Table 4.

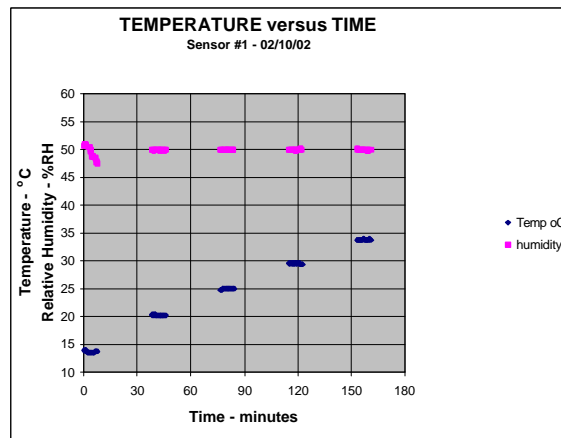


Figure 6: Temperature ramped

Table 3: Statistics of the temperature at set point

TEMPERATURE				
Sensor #1 - 02/10/02				
Set Point °C	Temperature °C	Standard Deviation	Sample Size	Confidence Level @ 95%
15.0	13.7	0.13	25	0.052
20.0	20.3	0.02	25	0.009
25.0	25.0	0.05	25	0.019
30.0	29.5	0.05	25	0.022
35.0	33.8	0.04	25	0.016

Table 4: Statistics for relative humidity

RELATIVE HUMIDITY	
Sensor #1 - 02/10/02	
Set Point	50.0
Mean	50.4
Standard Error	0.032
Standard Deviation	0.354
Range	0.5
Minimum	50.1
Maximum	50.6
Count	125
Confidence Level(95.0%)	0.062

3. TEMPERATURE-RELATIVE HUMIDITY SENSORS

The graph in Figure 7 shows the wavelength plotted against temperature for T-RH sensor #1. The linearity is good and has a slope of about 10 picometers per degree centigrade. The graph in Figure 8 shows the wavelength plotted against relative humidity. The slope is 3.2 picometers per one RH unit.

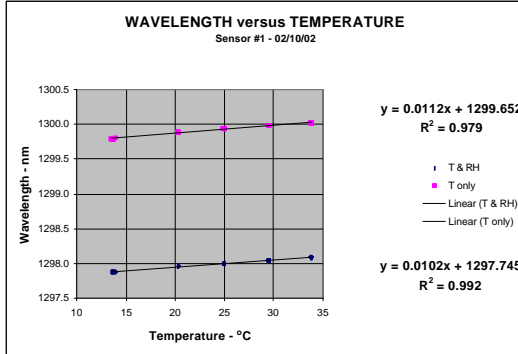


Figure 7: Wavelength vs. temperature

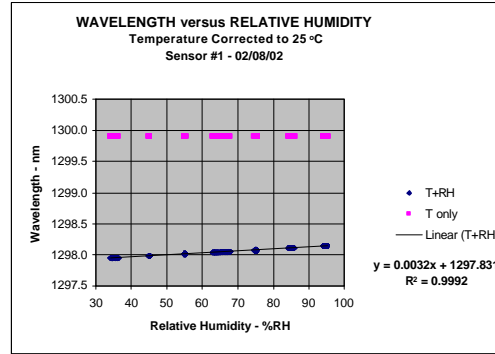


Figure 8: Wavelength vs. relative humidity

The equations from the graphs are shown below. Note that the temperature is held at 25 °C when ramping relative humidity and relative humidity is held at 50% when ramping temperature. The slope of the temperature grating for wavelength versus relative humidity is small enough to be neglected.

The equation for the temperature only grating is:

$$I_T = .0111T + 1299.651 \quad RH = 50\% \quad (1A)$$

or

$$T = \frac{1}{.0111} (I_T - 1299.651) \quad (1B)$$

Where λ_T is the measured wavelength from the temperature only grating.

The temperature plus relative humidity grating has the following temperature relationship:

$$I_{TRH} = .011T + 1299.652 \quad (2)$$

The temperature plus relative humidity grating has the following relative humidity relationship:

$$I_{RHT} = .0032RH + 1297.831 \quad (3)$$

The temperature obtained from a field measurement contains wavelength contributions from both temperature and relative humidity, thus:

$$I_{(T+RH)} = I_{(T)} + \Delta I_{(RH)} \quad (4)$$

The value for T obtained from equation 1B may be put into equation 2 to obtain the wavelength, λ_T , due to temperature alone and equation 3 can be solved for the relative humidity.

4. SOIL MOISTURE SENSOR

The graph in Figure 9 shows wavelength plotted against relative humidity for the soil moisture sensor. As seen in the figure, the sensor has a nonlinear humidity response with dramatic increases as higher humidity levels are approached. The large jump between 85% and 95% relative humidity is a result of condensation on the sensor. Due to the time response of the sensor to condensed water, it did not completely stabilize during this test. With this housing the humidity response at low humidity levels is relatively small. This sensitivity can be tuned during the manufacturing process to give a more dramatic response.

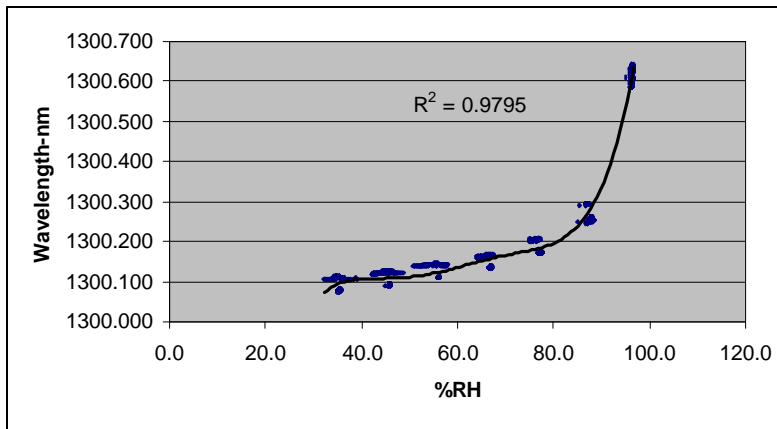


Figure 9: Humidity calibration for soil moisture sensor

For investigating the response of the sensor in the presence of condensed water, the sensor was submerged in a bottle of water and the response was recorded. The results of this test are shown in Figure 10. As seen in the figure, the immediate response to submersion was a 1.3 nm jump in wavelength, which was followed by approximately a 0.1 nm rise to the full response over the next two hours.

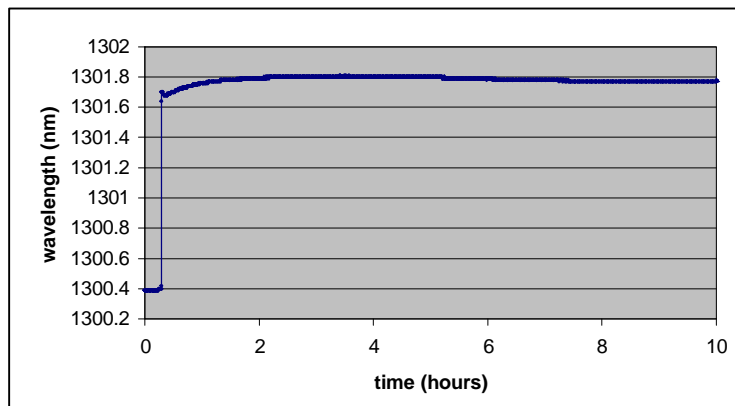


Figure 10: Response of the sensor for laboratory soak

In order to see the response of the sensor to soil moisture content, tests were performed using sandy loam soil that had been dried and then moisturized to a calculated percent water by weight. The moist soil was compacted into the lower half of a container and the sensor was positioned on top of it. Then, the rest of the container was filled and the soil was compacted. The response of the sensor was monitored for several days. Figure 11 shows the response of the sensor to 2%, 4%, and 8% soil moisture content. As seen in the figure, the higher moisture contents required approximately 30 hours to reach their full response.

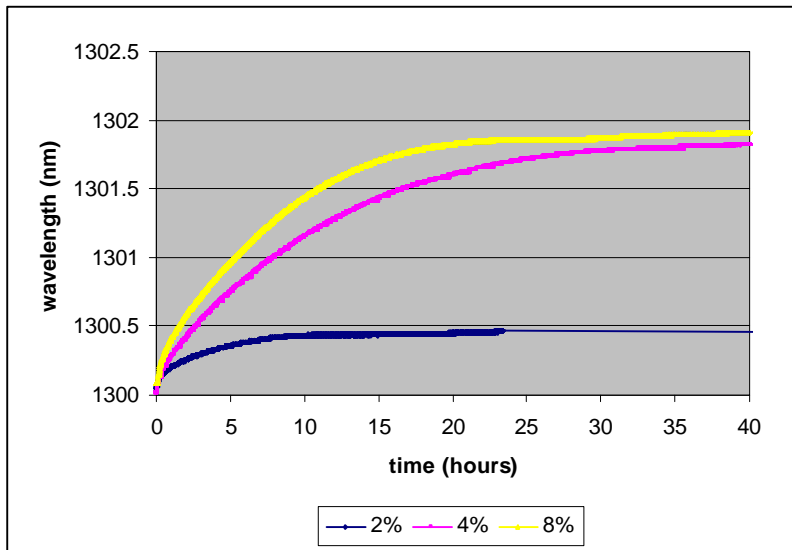


Figure 11: Soil moisture response of the sensor

As seen in the figure, the starting wavelength for the 8% moisture test was approximately 0.1 nm higher than the others. This was caused by the compaction of the soil around the sensor. The total response of the 8% and 4% tests were approximately equal. The soil compaction also allowed the response of the sensor in this configuration to be slightly higher than its response to being submerged water. From these tests, it appears that the limit of the moisture sensing appears to be between 2% and 4% soil moisture.

Finally, the sensor was soaked in water for several hours and then allowed to dry in room air. The drying time was approximately 4 hours, as illustrated in Figure 12.

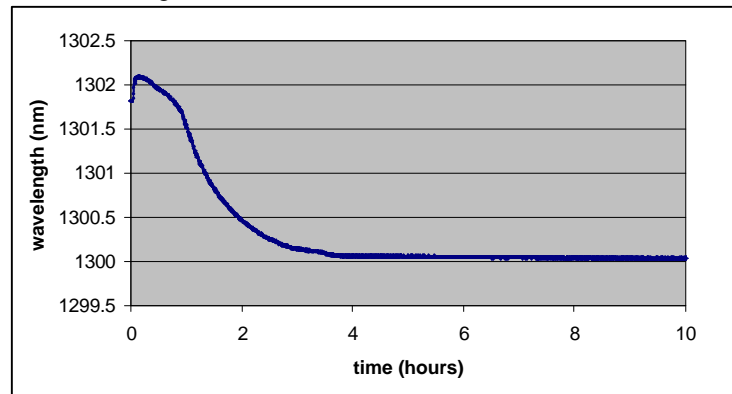


Figure 12: Drying response of the soil moisture sensor

From the tests that have been performed, these sensors seem to perform well in detecting the presence of water. Further tests will be required for accurate calibration for relative humidity and soil moisture content.

4.1 Field test data from an earlier configuration

With an earlier configuration of this type of sensor, a field test was conducted in which the sensors were buried in a soil lift and water was applied to the surface. The moisture content of the soil was measured with a neutron probe and the responses of the sensors were recorded. Figure 13 shows the test bed with the neutron probe as well as the response from both the neutron probe and the sensors.

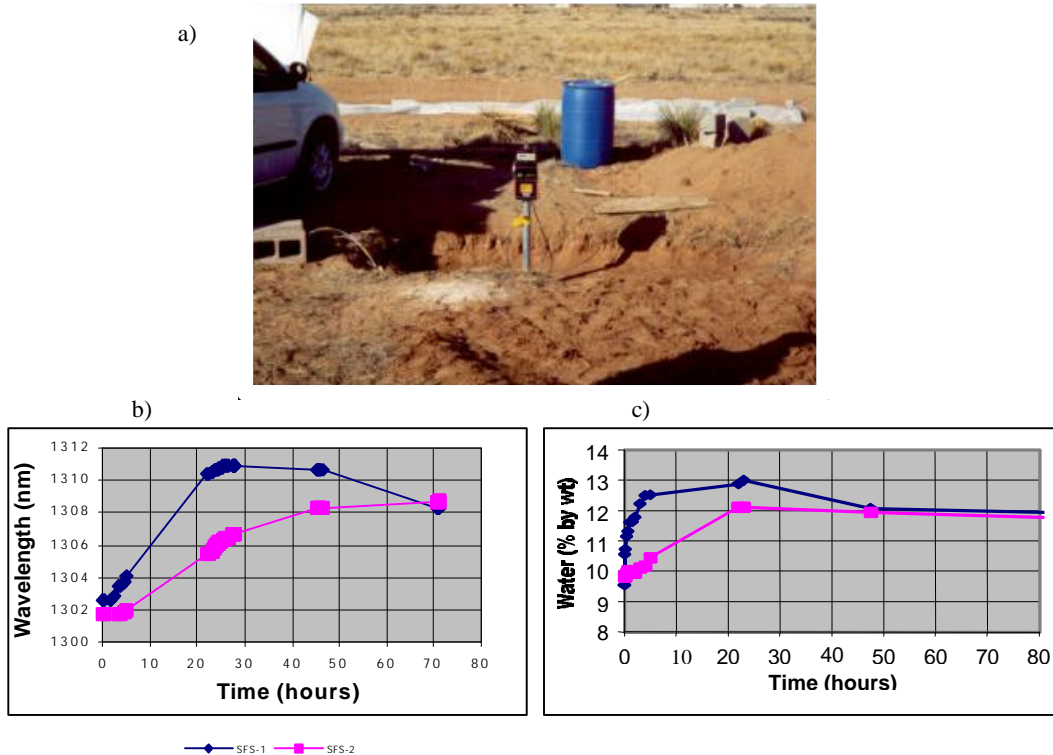


Figure 13: a) Field test site with the neutron probe, b) peak location response from the prototype sensors, and c) data from the neutron probe.

As seen in the figure, the general trend returned from the neutron probe and the sensors appear to match. The response of the sensors is related to the compaction of the soil around the sensor as well as to the response of the actuating medium in the sensor housing.

4.2 Soil moisture testing facility

As the moisture sensors continue to improve, more “real world” tests will be required to prove the technology. In parallel to the field tests, the sensors will be buried in a soil lift and flooded with water. Blue Road Research has constructed a soil moisture test facility at its Fairview, Oregon site. Four soil test boxes are protected from the weather in a greenhouse constructed on a gravel drain bed. Figure 14 shows the greenhouse and soil boxes. These will be used with a sandy loam soil to critically evaluate the performance of the moisture sensors.



Figure 14: Blue Road Research soil moisture testing facility: a) greenhouse and b) soil test boxes

5. SUMMARY

Blue Road Research is developing moisture-sensing technology that is capable of precision relative humidity and soil moisture measurement. While the sensors are currently in the research and development phase, we have demonstrated the performance of the technology and are moving toward commercially available products.

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