

An online humidity transducer based on near-infrared radiation

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Abstract. In various sectors, humidity measurement is a crucial task, for instance in the food industry, grain processing/crushing, sugar plants, etc. The conventional humidity measurement method requires a lab sample analysis. This is a destructive, expensive and slow process. Besides, as raw material humidity may vary considerably during the day, many measurements are required throughout the period. On the other hand, with an online humidity measurement process, the water amount is known instantly, without physical contact with the sample. Thus, the production process control can be carried out without losses, with maximum profit and quality. In this work, a humidity transducer based on near-infrared radiation is presented. During its development, the main project focus was cost reduction. Due to this, LEDs were used for producing infrared radiation. This has eliminated typical problems in conventional online measurement tools, such as reduced useful life and too many moving parts which may complicate equipment installation in vibrating places. Through the inclusion of a temperature control system, problems with ambient temperature variation were solved. The equipment was tested on a laboratory, measuring coffee powder humidity. However, the system can be easily adapted to measure humidity on a variety of other substances. Our tests indicate that the proposed transducer has a high sensitivity and robustness to temperature variations and external radiation sources (solar and incandescent light, etc.) Besides, the measured equipment uncertainty is in the order of 0.2 %.

Keywords: Measurement of Humidity, Near Infrared, NIR, on-line humidity meter.

Introduction

Grains, seeds and food are very perishable, but can be stored for a long time if treated adequately. Various factors are involved in maintaining product quality, but chief among them is humidity, since water is responsible for biological activity and chemical and physical changes. Reducing humidity therefore implies in the reduction of biological activity, the pace of chemical reactions and the development of microorganisms (Goneli et al., 2007). As humidity generally varies throughout the production process, ideally there would be continuous measurement of humidity across the entire production line. Instruments that can be employed to this end are termed "on-line humidity meter".

Commercial on-line meters don't work well in low or high temperatures. Hence, a transducer that is capable of measuring humidity directly in the production line, instantly and immunes to large variations in temperature, allows for immediate process adjustment to the desired value, preventing losses and reprocessing of product. If in addition the measurement system is small, low-cost and easily adaptable to any environment, it is feasible to install a series of transducers at various stages of the production process, reducing costs related to chemical measurements, infrastructure and labor, facilitating measurement and ensuring a greater control of the productive process.

In this context, we present a humidity transducer based on diffuse reflection in the near-infrared band. This transducer senses humidity through the identification of water molecule concentration using the principle of absorption/reflection. Absorption consists in the loss of energy of electromagnetic radiation going through a medium. Molecules in this medium absorb energy and change to an excited state, displaying specific transitions of its energetic conformation. These transitions supply a "signature" of the kind of molecule that exists in a certain medium, and by observing the reduction in intensity of the electromagnetic signal for the wavelengths correlated to these transitions, one can estimate the concentration of these molecules (Araujo, 2007). This is a common process which happens in different mediums such as solids, liquids and gases.

Proposed System

Unlike conventional systems which employ incandescent lamps as infrared radiation sources, the proposed system (Figure 1) uses LEDs (1) to emit radiation in water's absorption wavelengths (970 nm, 1200 nm and 1450 nm). This radiation shines over the samples and is absorbed by water molecules. The remaining non-absorbed radiation is reflected diffusely and collimated by a concave mirror (2) which focuses these radiations in a plane mirror (3) located 3 cm away from the focal distance of the concave mirror. This plane mirror reflects the focused radiation to the InGaAs-type optical sensor (4). The sensor is located in the center of the concave mirror, where a temperature control system (5) for the optical apparatus is installed. This is necessary due to the radiation sensor's high sensitivity to temperature changes.

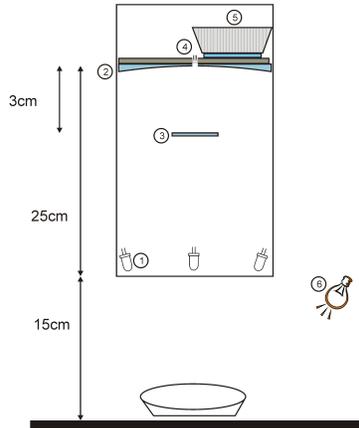


Figure 1: Diagram of a tree configuration.

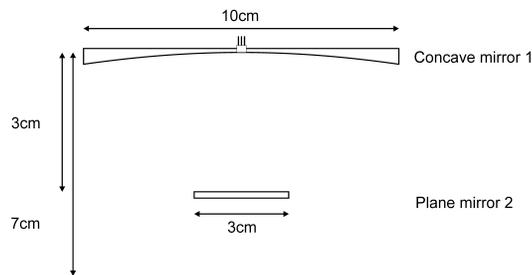


Figure 2: Mirror arrangement employed in the prototype.

The use of LEDs as an infrared radiation source has the advantage of not radiating heat, thus solving the problem of heating caused by incandescent lamps, decreasing the size and increasing the equipment's useful life, as an incandescent lamp has a shorter useful life. Another advantage of using LEDs is that it becomes possible to modulate the emitted radiation, removing the need for a mechanical chopper. This solves the problem of moving parts and by consequence the limitation of installation in places subject to vibration. Also, due to the light-emitting semiconductor having a very narrow emission bandwidth with low opening angle (focusing the emitted radiation), it isn't necessary to employ filters to select the desired wavelength. This leads to a cost reduction in the equipment.

To improve the system's sensibility and reduce the equipment's size, a mirror arrangement was employed as in Figure 2. A concave mirror is employed (Mirror 1) with a 10 cm diameter and 7 cm focal distance, as well as a plane mirror (Mirror 2) with 3 cm diameter. This arrangement also allows for fixing the sensor in a heat sink for heat exchange and temperature control, without getting in the way of the reflected radiation.

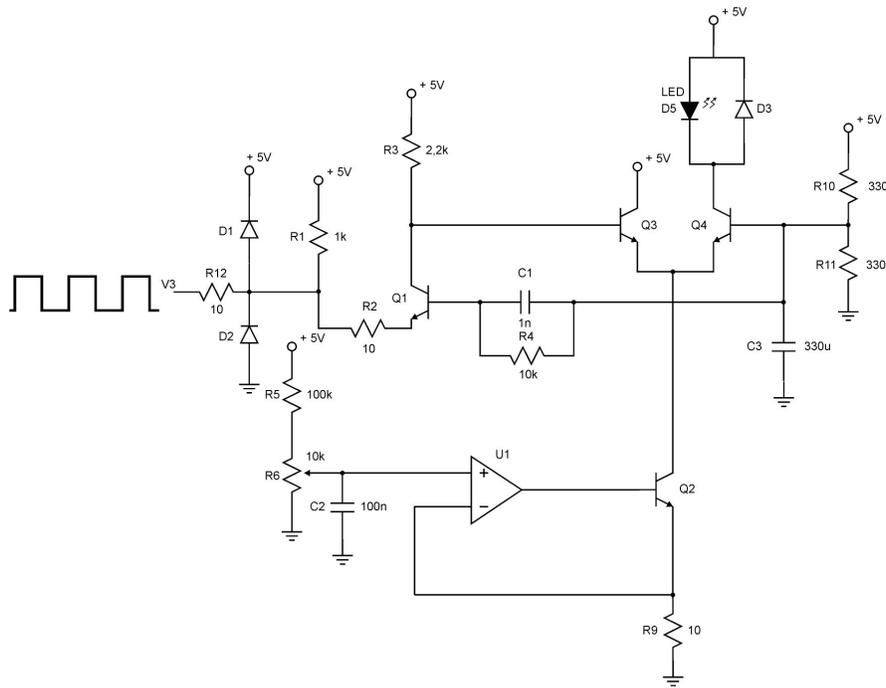


Figure 3: Circuit of the emitters.

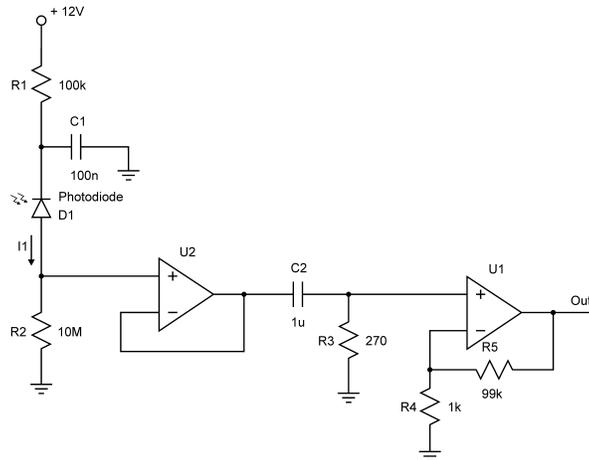


Figure 4: Circuit of the receiver.

Each of the three emitters used are triggered by circuits similar to that of Figure 3. In it, a microcontroller generates a TTL signal with 1 kHz frequency, which is used to control a current source that regulates the LEDs' emission power. The current source is based on the LM324 operational amplifier. The voltage in R6 determines the current in R9, which will be the same as Q2's emitter current.

The transistors Q3 and Q4 are connected as a differential pair. The emitters supply all current to Q2. Whichever transistor has higher base voltage will be responsible for supplying all current to Q2. When Q3's

base voltage is higher than Q4's base voltage, then Q2's current is supplied by Q3 through the voltage source. When Q4's base voltage is higher than Q3's base voltage, then Q2's current is supplied through Q4, which will drain current through the LED, activating it. In Figure 3 the emitters' block is presented.

Since the signal received by the sensors is very weak, being the result of diffuse reflection of light over the sample, an amplifier circuit is called for. This is shown in Figure 4. The circuit receives the sensor's signal, converts it to voltage, passes it through a high-pass filter to eliminate external interference (the desired signal is modulated while the interference signal is continuous) and applies a 100-fold gain to the original signal. Also, in Figure 4, the first operational amplifier (an OP07E) was used as a buffer so that the signal can pass through the filter. Capacitor C2 and resistor R3 are used to filter DC signals, so that only AC signals are amplified. Next, the filter is configured with a cutoff frequency of 600 Hz, to prevent interference from fluorescent lamps, whose reactors are supplied from mains power with a 60 Hz frequency and hence with 120 Hz harmonics. The second operational amplifier is configured in a non-inverting topology with a gain of 100.

After the circuit of Figure 4, a peak detector circuit is used. In it, the sampled peak is proportional to the amount of radiation received by the InGaAs sensor and corresponds to the output of the proposed transducer.

For temperature control, which was employed to keep the temperature of the InGaAs sensor at a constant 25 degrees Celsius, an LM35 temperature sensor was used along with a proportional controller implemented with an LM324 operational amplifier. The amplifier's output is applied to a Peltier element in contact with the sensor which cools or heats it.

Experimental results

The developed transducer still needs to be calibrated. Calibration involves associating humidity values with voltage signals at the output of the infrared receiver circuits. It's necessary to perform a calibration for each kind of material of interest (soybean grains, sugar, paper, etc.) However, as shown next, it is already possible to evaluate the developed transducer in several aspects.

To perform tests, the chosen material was coffee powder, acquired in the local market of the town of Londrina, Paraná, Brazil. Samples were separated in portions, which were moistened with a varying quantity of water. Next, they were left at rest for about 2 hours to obtain an uniform humidity distribution. Also, in every case, for comparison with the proposed transducer, the reference method chosen for humidity calculation was the Brazilian standard oven method established by the Ministry of Agriculture, Livestock and Food Supply (Almeida et al., 2007; Fogaça et al., 2004; Luz et al., 1993; Nery et al., 2004; Pinho et al., 2007; Valentini et al., 1998), which is internationally recognized by International Seed Testing (ISTA) (Fogaça et al., 2004; Luz et al., 1993; Nelson et al., 2000; Nery et al., 2004).

For acquisition of transducer output signals, a workbench precision 6.5 digit multimeter was employed, plus a virtual instrument developed with LabVIEW software. The data acquisition program allows for configuring the resolution and number of samples, and saves the data in a text file for later analysis.

During measurements, samples were placed in glass jars in a sufficient amount to ensure complete coverage (to avoid radiation reflection in the glass) and placed in the center of the tube, about 15 cm away from the emitters.

Next we present test results.

Sensitivity test

In this test, we aim to evaluate the voltage variability in the output of the transducer as a function of humidity. To this end, we performed a series of measurements of the same sample, with a ten minute interval between each measurement. In these tests, we performed 2,000 acquisitions for each water absorption band, with a sampling rate of 1 kHz. Next, the median of the 2,000 acquired points was used to generate a single result, in order to visualize the characteristic curve with the three water absorption bands. This plot is presented in Figure 5 with different humidity values. An inversely proportional variation of signal amplitude with humidity can be verified. For the first water absorption band, amplitude variation is of about 3.52 mV per 1% of change in humidity, with a standard deviation of 0.00032 mV. In the second band, the variation is of 2.94 mV with standard deviation 0.00042 mV. At last, in the third band, variation is of 3.69 mV with standard deviation 0.00068 mV. However, if deemed necessary, sensitivity can be increased by adjusting the gain of the receiver circuit.

Repeatability evaluation

In this test, the system's capacity to produce the same results for the same sample was evaluated. Initially the measurement's time stability was looked at. In order to analyze the repeatability of these data, after performing measurements in the three bands, a period of 10 minutes was allowed to elapse before new

measurements were carried out. Another measurement was performed after shutting down the system and, after turning it on again, letting another 10 minutes elapse. In this test, using a sample with 9.1% humidity, for the 970 nm, 1200 nm and 1450 nm bands, a variation in the transducer output of 0.31%, 0.10% and 0.04%, respectively, was observed. The same test was repeated for other amounts of humidity and the results were very close. This shows that the transducer has great repeatability properties and is very stable.

Evaluation of immunity to light interference

To analyze the influence of external radiation sources in the proposed system, a 5W/12 V incandescent lamp was employed (6) according to Figure 1. This lamp was used to assess differences in measurements in the presence or absence of external radiation. For samples with 9.1% and 3.9% humidity, a difference of merely 500 μ V was observed in the transducer outputs. This shows that the proposed system has good immunity to external light interference, removing the limitation of installing the equipment in open locations.

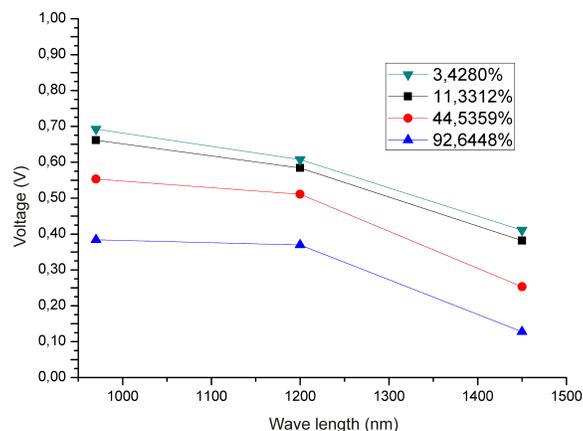


Figure 5: Values obtained from the proposed equipment in the 3 water absorption bands.

Conclusions

Humidity measurement and control are highly important to many areas of industry, for ensuring the maintenance of product quality in storage as well as to ensure the quality of the final product in the production process, and also to prevent losses and hence obtain better profit.

Existing on-line humidity transducers have usage restrictions which severely limit their usefulness in industries. Among these restrictions are: interference of external light sources, impossibility of being installed in locations with vibration and environment temperature variation, large size and high cost.

In this paper, we presented a humidity transducer which can be employed in the development of an on-line humidity meter which solves most of the aforementioned problems. This transducer's operating principle is based in the use of semiconductors (LEDs), in place of incandescent lamps which require mechanical choppers (to modulate emitted light) and optical filters (for wavelength selection), and hence solves the problems of size, installation limitations and also reduces cost.

As experimental results show, the use of multiple water absorption wavelengths, plus amplification and signal conditioning circuitry, solve the problem of external interference. Besides, temperature control using a Peltier element solves the problem of temperature variation. It follows that the developed transducer will be very useful to improve performance of infrared humidity measurement meters.

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