Full Paper

DETERMINATION OF BULK GRAINS MOISTURE CONTENT IN A SILO USING DISTRIBUTED SENSOR NETWORK

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ABSTRACT

This paper presents a solution to the problem of determining the moisture content of bulk grains stored in silos. A distributed sensor network was designed to achieve this. The network consists of sensor nodes and a sink node connected to a Personal Computer (PC) through a USB port. The sensor nodes were calibrated using standard saturated salt solutions.

Data collection, analysis and logging were achieved with Graphical User Interface (GUI) developed using LABVIEW graphical programming software. The distributed system was then evaluated with reference to the standard test values established against the oven-drying method. This study concluded that its approach provides improved flexibility and control in measurement of moisture content of grains over the existing stand alone meters.

Keywords*: Grains, Moisture content, Sensor node, Sink node, GUI, LABVIEW*

1. INTRODUCTION

Storage of grains is an important post-harvesting process in agricultural practice. A safe storage activity must be ensured for the grain produced until it is needed for consumption, multiplication, further processing and commercial purposes. Globally, around 2.4 billion tonnes of grains are produced annually, out of which only 43% are consumed (Jayas *et al.*, 2000). Since grain production is seasonal and consumption is continuous, safe storage must maintain grain quality and quantity. This means that provided the grains are not invaded by insects, mites, rodents, or birds; grains have to be protected from mold infection, heat build up, odour development and microorganisms (Jayas *et al.*, 1995). These infections do develop from unnecessary high moisture content (MC) caused by inadequate drying or moisture rebounds in the stored bulk grains. However, environmental conditions like uneven temperature distribution and humid air flow in the silo (store house) can cause stored grains to develop higher MC, which needs to be adequately measured and controlled.

Measurement of MC of grains stored in silos had previously encountered many problems which include static charges that develop in bulk grains with its accompanying health hazard to the monitoring personnel, and the temperature at different points in the silo is always different thereby rendering the results obtained from instantaneous measurement of moisture content of the grains inaccurate for decision making.

Several approaches and methods had been adopted in determining the MC of grains in silos. These include: oven heating, desiccant, and distillation, microwave spectroscopy, resistance and conductivity, impedance, equilibrium relative humidity, and nuclear magnetic resonance methods. However, there had been observable inherent limitations and problems associated with the methods. These problems include: destructive tendencies in the tested samples, untimely discovery of the infested section of the grains in schedule measurements due to its non-continuous approach, and uneven air flow within the storehouse which makes the localized testing approaches insufficient. Also, if grains are to be held for months, most of these methods are not prudent to continuously or periodically monitor the different portions of the bin, test them for moisture content and examine them for fungal damage. Also, an efficient measurement technique must be cost effective, requiring rapid and accurate evaluation of the moisture content; a test which most of these techniques do not pass.

The application of distributed sensor network in different fields, including agriculture has made it a potential approach with hope of eliminating most of the limitations in the previous methods of MC determination. As discussed by Singh *et al.* (2010), wireless sensor network (WSN) is widely considered as one of the most important technologies for the twenty-first century. A WSN typically consists of a large number of low-cost, low-power, and multi-functional wireless sensor nodes, with sensing, wireless communications and computation capabilities. These sensor nodes communicate over short distance via a wireless medium, and collaborate to accomplish a common task, for example, environment monitoring, military surveillance, and industrial process control. The basic philosophy and advantages behind WSNs is that, while the capability of each sensor node is limited, the aggregate power of the entire network is sufficient for the required mission.

In applying distributed sensor network to solve MC measurement, the indirect equilibrium moisture content method would be adopted. Ray *et al.* (2007) describes this method, using hardwood as a case study, as measuring the relative humidity (RH) in the air space between the target products. The RH in the air surrounding a grain sample at any particular temperature (T) is dependent on the moisture content of the grains. According to Armstrong and Weiting (2007), grain equilibrium moisture content (EMC) prediction is particularly attractive in some applications considering the availability of inexpensive and reliable sensors to measure relative RH and T. Although EMC relationships are grain – type hybrid, or variety specific, and are affected by agronomic conditions, the ease of measuring RH and T with modern sensors makes the use of these relationships attractive for monitoring stored grain. It used SHT75 RH/T sensor with ChungPfost equations to design an instrument for evaluating equilibrium moisture content of grains. The design adopted wired, localized and instantaneous measurement approach. Chen (2001) determined that a measurement time of 10mins was required for the RH and T sensor he studied to equilibrate to the grain environment for accurate measurement.

Meanwhile, no single equation is general enough to predict the relationship between the EMC of agricultural and food products, and the relative humidity over a wide range of temperature (Brooker *et al.*, 1974; Chang *et al.*, 1993; Basunia *et al.*, 1996; Soysal and Oztekin, 1999; Lucas and Alabadan, 2002; Park *et al.*, 2002; Lahsasni *et al.*, 2004).

The HendersonThompson (Thompson *et al.*, 1968) and ChungPfost equations (Chung and Pfost, 1967; Pfost *et al.*, 1976) are satisfactory models for most starchy grains and fibrous materials. The Halsey equation is an adequate model for products having a high oil and protein content (Halsey, 1985). The modified Oswin equation (Chen, 2001) has served as a good model for popcorn, maize cobs, peanut pods and some varieties of maize and wheat. According to Soysal and Oztekin (1999), the GuggenheimAndersondeBoer (GAB) equation is considered the most versatile model for various materials such as inorganic and food products like fruits over a wide range of water activities.

Our study aimed at developing a system for determining MC of bulk grains in a silo using distributed wireless sensor network consisting of sensor nodes and a sink node connected to a PC, and evaluating the measuring system developed by comparing the results with existing systems. Our system made use of the modified Oswin model to express the MC in terms of the RH and T from its sensor nodes.

2. DESIGN AND METHOD

A distributed system of sensor network for MC measurement was developed for bulk grains in a silo. This consists of sensor nodes and a sink node (central hub) being connected to a PC.

2.1. Sensor node

The sensor node contains a programable Temperature/Humidity sensor SHT21 connected to a microcontroller unit (MCU) on a eZ430-RF2500T target board from Texas Instrument. SHT21 is a tiny humidity/temperature sensor made by Sensirion AG, Switzerland. It provides calibrated, linearized signals in digital, true I^2C format. It has a capacitive type humidity sensor and a band gap temperature sensor that produces a stable output even at moderately high humidity levels. SHT21 also contains an amplifier, A/D converter, and one-time programmable (OTP) memory and a digital processing unit. It works at (0 - 100)%RH and (-40 to 125)^oC, but gives a constant relative humidity value between 20 and 80%RH and constant temperature within 20 to 40^oC. It is designed mainly to work within a normal operating range of between (0 - 80)%RH. The sensor has a rated RH accuracy of ±1.8% RH and T accuracy of 0.3^oC. eZ430-RF2500T target board contains the MSP430F2274 microcontroller, CC2500 2.4-GHz wireless transceiver, and radio antenna.

The programming flowchart of the sensor node is as shown in Fig. 1.

The sensor nodes were calibrated using five different saturated salt solutions (NaCl, KCl, $NaNO_3$, K_2CO_3, and K_2SO_4) at temperatures of 5^oC, 10^oC, 15^oC, 20^oC, 25^oC, 30^oC and 35^oC. The RH values of the solutions with corresponding temperature values are compared with the literature values (Greenspan, 1977).

2.2. Sink node

The sink node is made up of eZ430-RF2500T target board, but was connected to the PC through the USB debugging interface. The USB debugging interface enables the eZ430-RF2500T to remotely send and receive data from a PC using the MSP430 Application UART.

All the calibrated sensor nodes are networked to a sink node using a Texas Instrument low-power RF SimpliciTI network protocol. The sensor nodes are programmed to communicate their sampled T and RH to the hub. The sink node communicates all collected data to a Personal Computer (PC) through its available serial port. The flowchart of the network is as shown in Fig. 2.

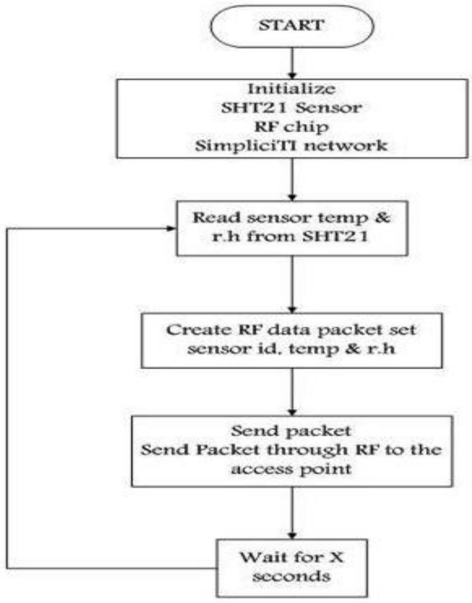

Figure 1: Flowchart of Sensor Node

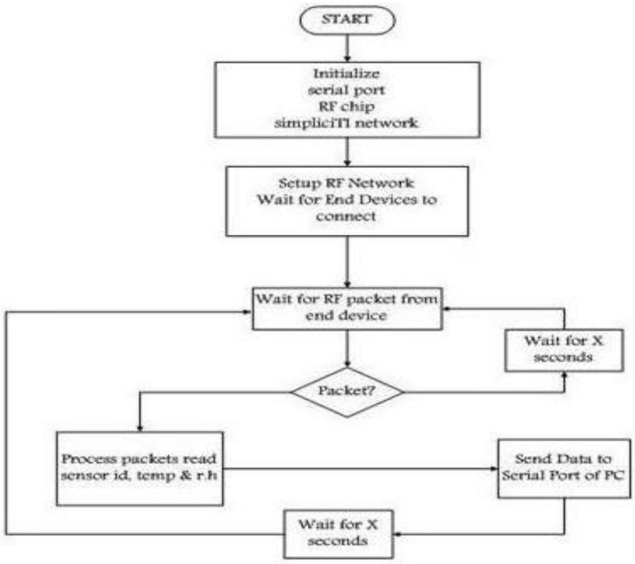

Figure 2: Flowchart of Sensor node – Sink node network

2.3. Graphical User Interface (GUI)

The GUI was developed with LABVIEW graphical programming software. It collects data from the hub, displays, processes and logs it into a file. EMC (dry basis) was computed using the Modified Oswin Model (Equation 1) for shelled corn grain. Modified Oswin coefficients used were from ASAE Standards D245.5 where a = 15.303, b = -0.10184, and c = 3.0358. The programming flowchart of the sink node to the PC is as shown in Fig. 3.

$$M = (a + bT)\left[\frac{R_h}{1-R_h}\right]^{1/c} \quad (1)$$

where: R_h – Relative Humidity (%RH), T – Temperature (^oC), M – Moisture Content (%MC), a, b, and c – constants.

The illustration of the network system is shown in Fig. 4, while the block diagram of the design as well as the implemented sensor node are as shown in Figures 5 and 6 respectively.

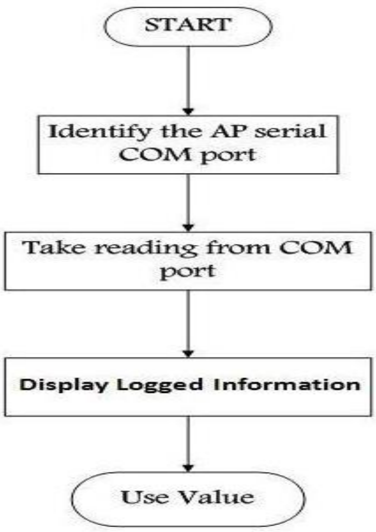

Figure 3: Flowchart of Sink node- Personal Computer (PC)

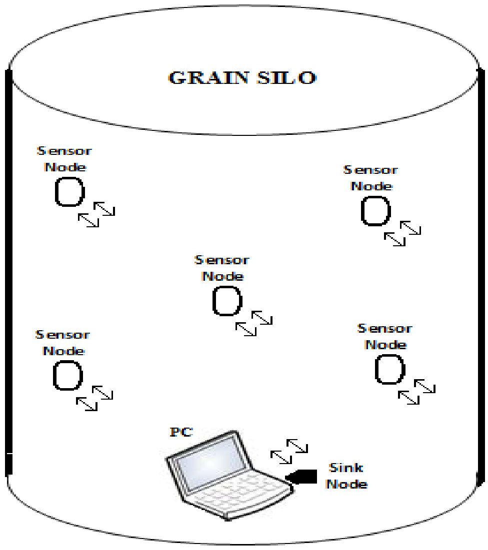

Figure 4: The Distributed System of Sensor Network

3. RESULTS AND DISCUSSION

The results of the calibrated values of the sensor node are as plotted against reference relative humidity values according to Greenspan (1977) in Fig. 7 – Fig. 11.

The results indicate relative agreement with the literature values. For NaCl and $NaNO_3$, the data are in good agreement with the study by Greenspan (1977). For KCl and K_2CO_3, the data fairly agree up to 55% with the Greenspan's study. There is no agreement among the system data and that of Greenspan (1977) for K_2SO_4. This is due to the inability of the SHT21 sensor used in the study to operate in the 90 - 100 %RH range. Overall, the trends shown by our data for these salts are in good agreement with the literature, demonstrating that the method used in this study is suitable for studying the relationship between RH and T, for RH ‹ 90%.

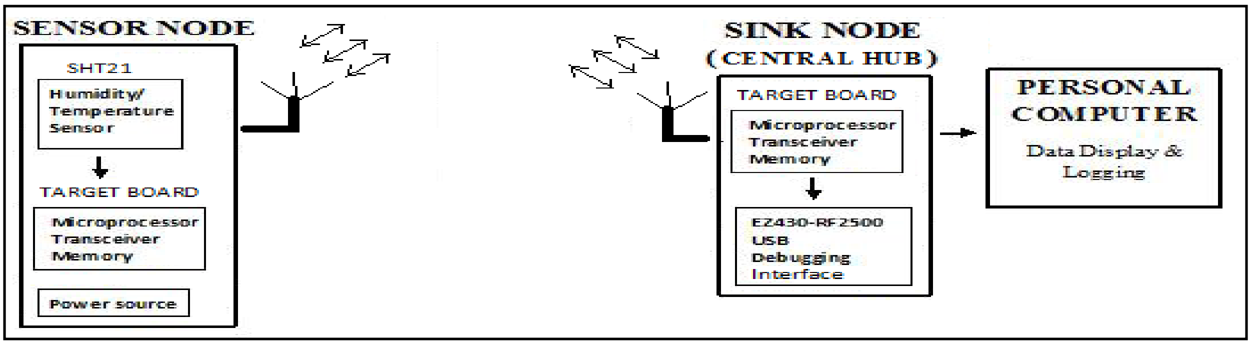

Figure 5: Block Diagram of the Wireless Sensor Network

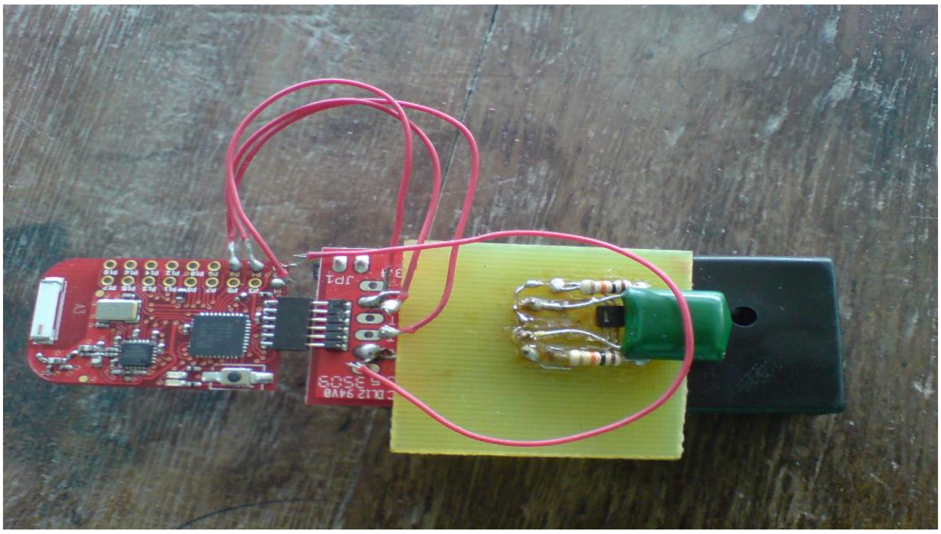

Figure 6: Sensor node

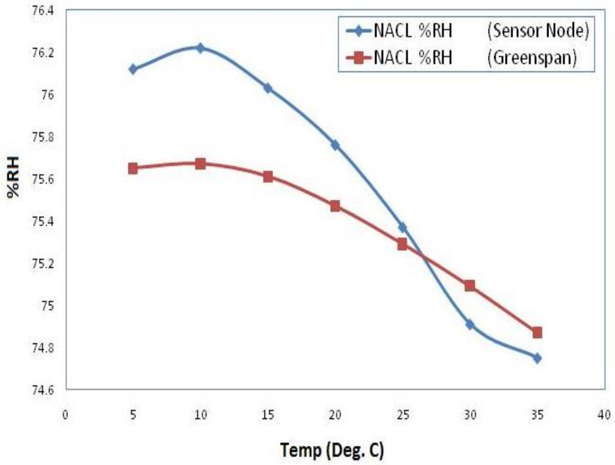

Figure 7: Relative Humidity of NaCl against Temperature

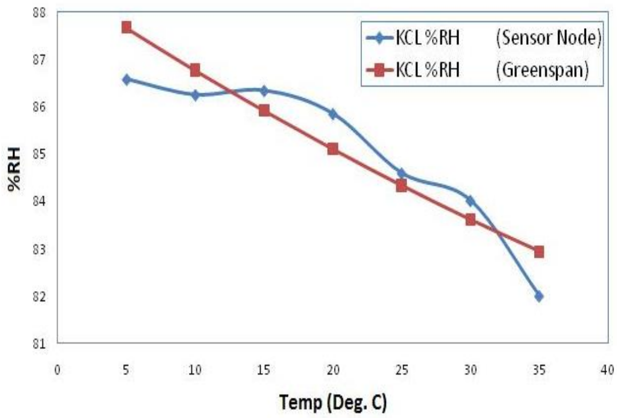

Figure 8: Relative Humidity of KCl against Temperature

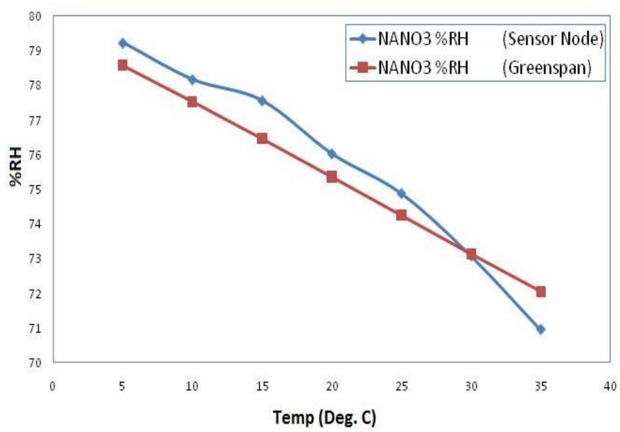

Figure 9: Relative Humidity of NaNO3 against Temperature

On the GUI, the communication port of the sink node connected to the PC is specified in the 'Device Port'. When the system is switched on, the readings of T, RH and MC in each sensor node are as indicated and plotted on the waveform graph. The stream of data is shown on the display desk, while 'MC Threshold' control is used to set the threshold of save storage MC. Whenever the MC › $MC_{Threshold}$ in any of the node, 'ATTENTION' is called for on the display desk and in the particular node as shown in Fig. 12.

The data are then logged into a file with the actual absolute time. The logged result of the system with MC › $MC_{Threshold}$ in node 1 and node 3 unavailable is as shown in Table 1 of the Appendix.

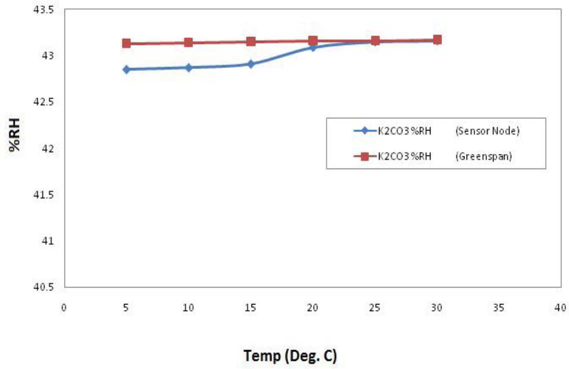

Figure 10: Relative Humidity of K_2CO_3 against Temperature

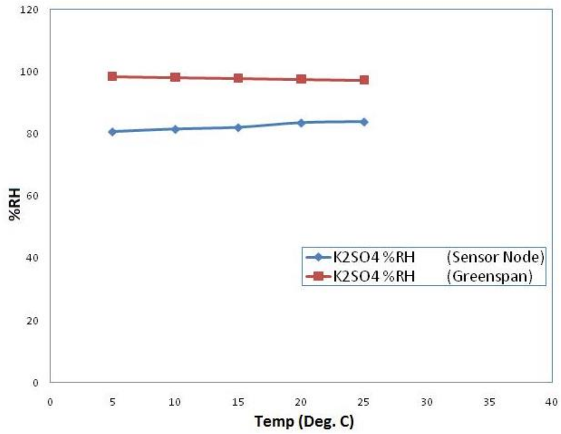

Figure 11: Relative Humidity of K_2SO_4 against Temperature

4. CONCLUSION

A reliable approach in the determination of the moisture content of stored grains had been developed using a distributed system of sensor network. The relative agreement of our calibrated values with the literature values confirms the viability of our method to determine the temperature and relative humidity distribution in a silo.

The advantages of our method include non-destructive approach of the grain samples, continuous measurement and monitoring of the grains, distributed measurement across the strata of the grain bins as against previous localized approach, and remote monitoring of the grain condition which prevent health hazard of the personnel.

The system would not operate effectively for relative humidity greater than 90%, which is an extreme case beyond useful grain storage.

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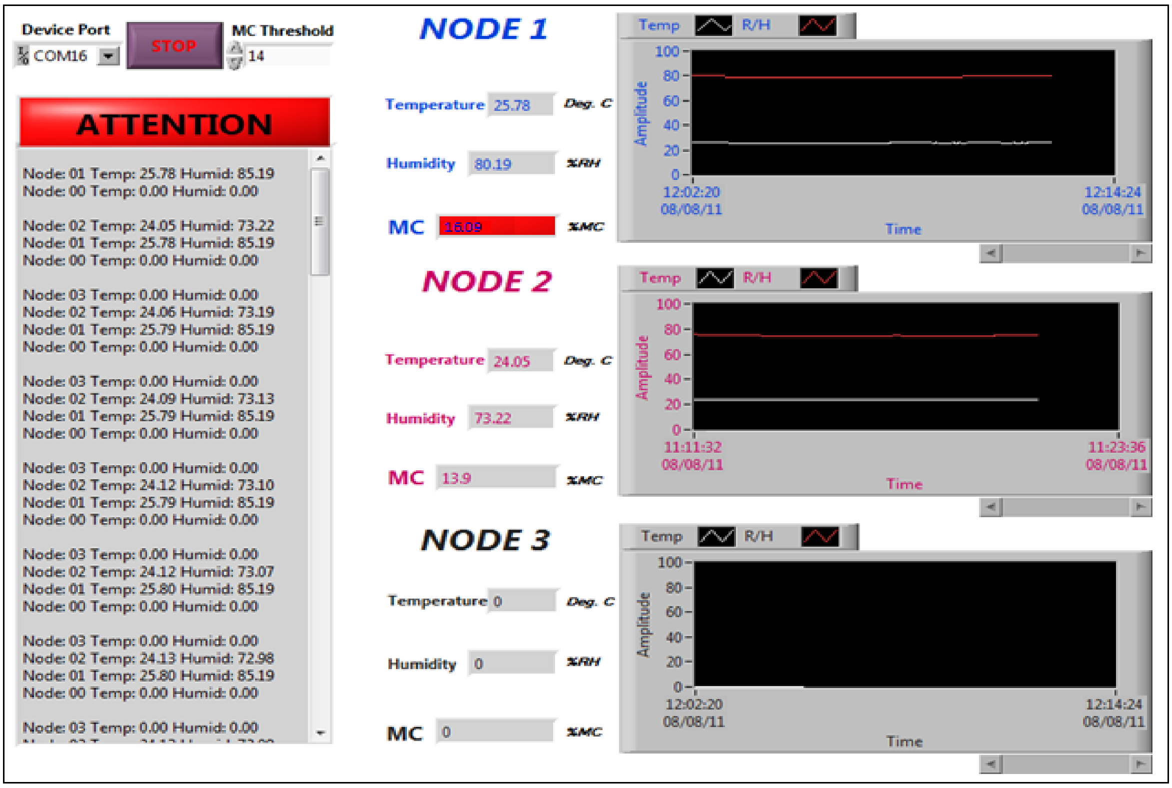

Figure 12: GUI Display during operation

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