A Wireless Sensor Network for Controlling the Effect of the Moisture Content in Stored Maize Grains

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Abstract--- **In ensuring that the quality of stored maize grains is protected against mold infection, heat buildup, odour development and microorganisms which are the causative agents of spoilage, the moisture content (MC) of the grains need to be well monitored and controlled. Meanwhile, moisture content is directly dependent on some basic environmental factors which in-turn affects the quality and economic value of the grains.**

This paper presents a wireless sensor network (WSN) solution to the problem of correctly determining and controlling the effect of MC on stored bulk maize grains. The study hereby presented, characterizes a sensor node and develops a measuring system consisting of network of calibrated sensor nodes and a coordinator. Data values for the moisture content of the grains were collected from the nodes at different locations of the storage bin and wirelessly communicated to the central hub consisting of the coordinator and personal computer (PC). LabVIEW programming software was used to develop a graphical user interface (GUI) for collection, logging and analysis of the data. The system indicated an alert whenever the MC of grains at any of the nodes exceeded the set limits for good maize storage condition. This helped the administrator to initiate aeration for mitigating the effects of high MC. This study concludes that the reported approach is more suitable for studying the relationship between moisture content, relative humidity and temperature, and provides improved flexibility and reliability in measurement and control of moisture content of grains.

Keywords--- Maize grains, Wireless Sensor Network, Moisture content, LabVIEW.

I. INTRODUCTION

Production of maize grain is seasonal but the consumption is essentially continuous. The storage of the grain must however be ensured safe until it is needed for consumption, further processing or commercial purposes. The spoilage of stored maize grain is caused by various infections, except for possible invasion by pests [8]. These infections do develop from unnecessary high moisture content (MC) caused by inadequate drying or moisture rebounds in the stored volume. Most grains like maize are usually harvested at 20−25% MC while 14% or less is considered safe for storing the grains [5]. For storage, it is the highest moisture content that is present in the grain mass that determines to what extent and how fast storage fungi will develop and damage the grain. However, environmental conditions like uneven temperature distribution and humid air flow can cause higher MC to develop across the stored grains. The relative humidity (RH) in the air surrounding a grain sample at any particular temperature (T) is dependent on the MC of the grains. It is therefore vital to correctly measure and control the environmental conditions for ascertaining the quality of the grains, maintain competitive advantage in the food processing industry, and ensure food security [10].

Determining moisture content accurately is extremely important to those who produce, handle, and process corn. The common practice in determining MC is using samples to describe the entire moisture content of a bin of grains thus assuming a uniform distribution of moisture throughout the whole bin. However, representative samples taken from a storage bin do not provide the range of moisture present within the bulk. For safe storage, it is essential to know the highest moisture content in any portion of the stored grain mass at every location, and at any given time. Moisture content of grains in some areas of the bin may differ by several percentage points from that shown on the records. Because even if the grains are of uniform moisture content and well mixed when they are loaded into the bin, differences in temperature within the grain mass, insect activity, and mold growth may result in moisture transfer [4]. In post-harvest handling, grain MC is generally stated on a wet weight basis, meaning that it is expressed as percentage of water contained in the grain [7].

Different methods had been developed for determining MC of grains. However, if grains are to be held for months, it is not prudent in 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, a measurement technique must be cost effective, requiring real-time and accurate evaluation, and decision making on the moisture content [9]; a test which most of these techniques do not pass. A more viable technique is hereby reported a distributed approach of wireless sensor network.

Wireless Sensor Network (WSN) has in recent years been found to have vast application in various areas; from agriculture to utilities and in remote monitoring [12]. A WSN is a network made of a set of independent sensor nodes deployed over a geographic area to collect environmental data and to transmit the gathered data to a base station typically through wireless channels. A sensor node consists of sensing, computing, communication, actuation, and power components [2]. The base station is generally a computer connected to a gateway, which is a device that collects data from the sensors. An application running on the base station analyzes the received data, performs appropriate computation, and displays the information on the user interface for further decision making [13].

II. DESIGN AND METHOD

The WSN was designed and developed with various hardware and software units.

A. Hardware Unit

The hardware unit included sensor nodes also being referred to in this paper as end devices (ED) to be located at different locations within a bulk grains storage facility, and being connected to a central hub or access point (AP) through RF link by their respective transceivers. The AP which was the network coordinator had its received data accessed through the USB port of a Personal Computer (PC). The architecture of the entire design is as shown in Fig 1.

a. End Device

Each sensor node was developed with SHT21 (Temperature/Humidity Sensor manufactured by Sensiron AG, Switzerland) and an eZ430-RF2500T target board from Texas Instrument consisting of MSP430F2274 microcontroller, CC2500 2.4-GHz transceiver, memory and chip radio antenna as shown in Fig 2. The sensor provides calibrated, linearized signals in digital, true I^2C format. It works at (0 – 100)% RH and (-40 to 125)^{0}C with accuracy of 1.8% RH and 0.3^{0}C. The end device was being powered by 3Volts AAA batteries.

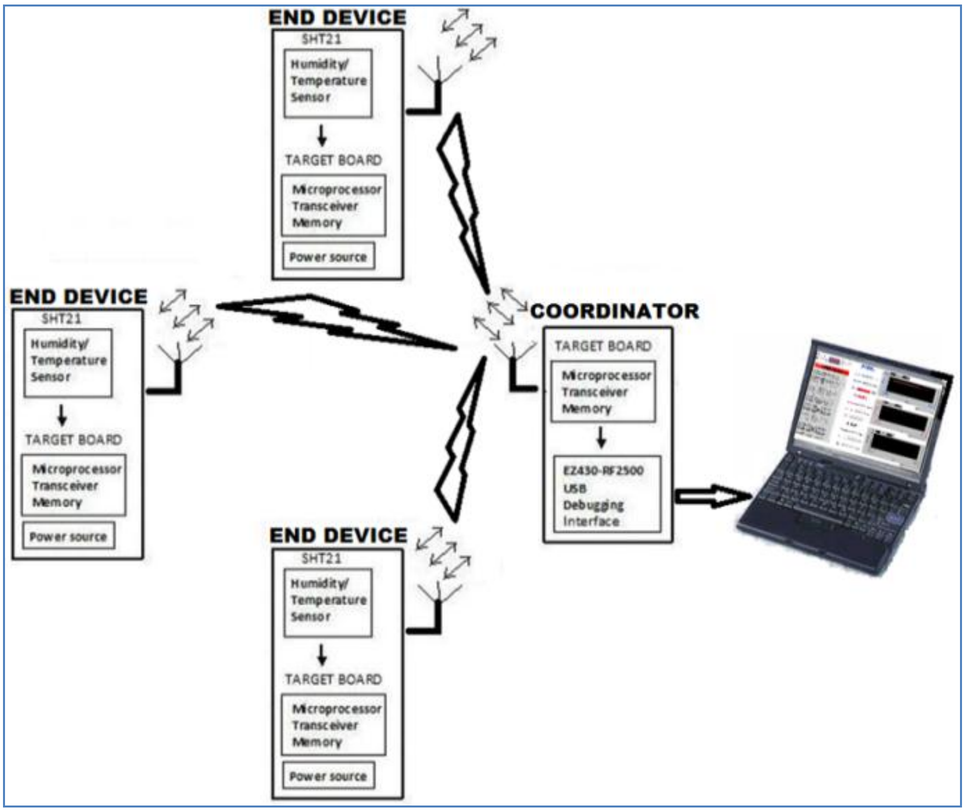

Fig 1: The WSN System Architecture

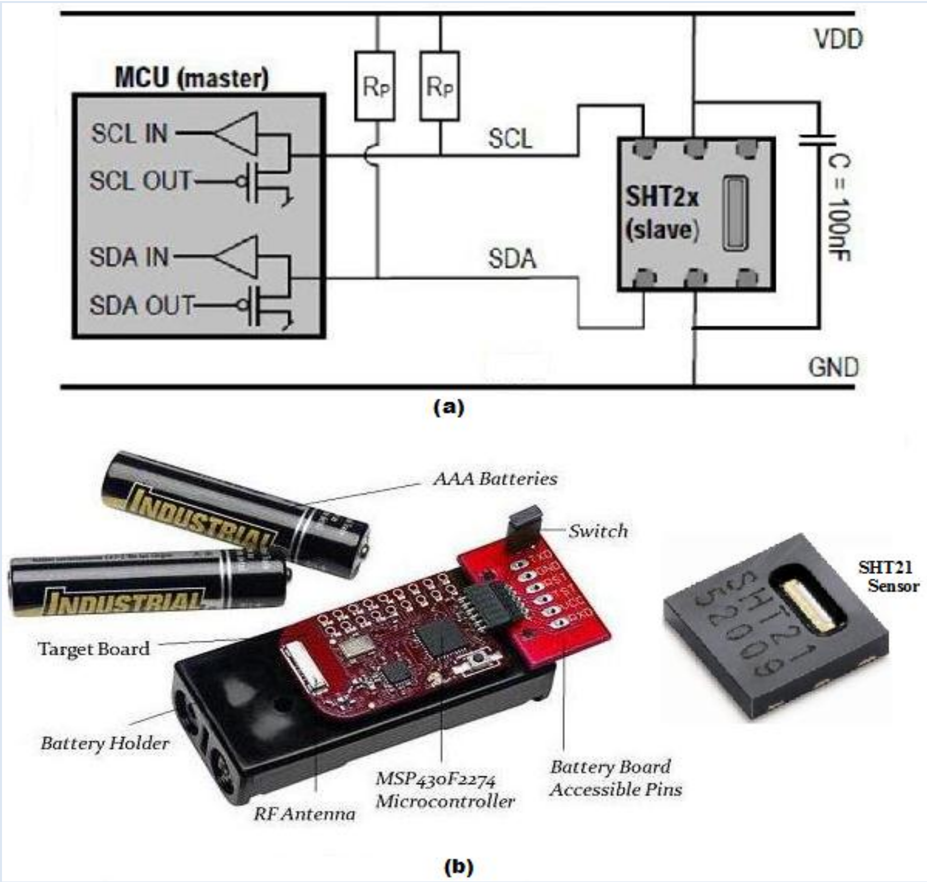

Fig 2: (a) Schematic Diagram of Sensor –MCU (b) Components of an End Device

Characterization of the End Devices

The characterization of the end devices was done using saturated solutions of five different salts: NaCl, KCl, $NaNO_3$, K_2SO_4, and K_2CO_3 at temperature from 5^0C to 35^0C and step increase of 5^0C.

b. Network Coordinator

The access point (network coordinator) consisted of one target board similar to the one in the end device, and a USB enabled MSP430 application universal asynchronous receiver/transmitter (UART) as shown in Fig 3. This was connected to a PC, and the USB debugging interface enabled the eZ430-RF2500T to remotely communicate with each end device to receive its data.

B. Software Unit

The interaction of the sensor with the ED, the communication network of the EDs and the coordinator, the data collection from the AP through the PC and the alert given to the storage bin administrator were achieved using software applications. The flowcharts of the software design in the nodes and the network are as shown in Fig 4. The network of the nodes and the coordinator was achieved using low-

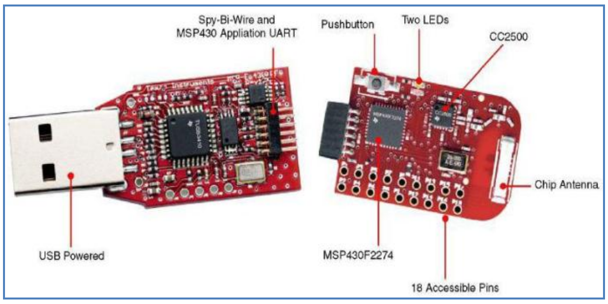

Fig 3: Coordinator Unit

power RF modified SimpliciTI network protocol. A graphical user interface (GUI) was developed with LabVIEW. The GUI was designed for the collection of the data from the serial port of the PC, processing and analysis for MC determination, logging and display of the data, and indicating alert for administrator's attention when necessary. The LabVIEW signal block diagram of user interface is as shown in Fig 5.

The setup of the wireless sensor network is as shown in Fig 6 with the composite units indicated. The second diagram labeled 'B' is the enlarged view of each end device shown in the first diagram 'A'.

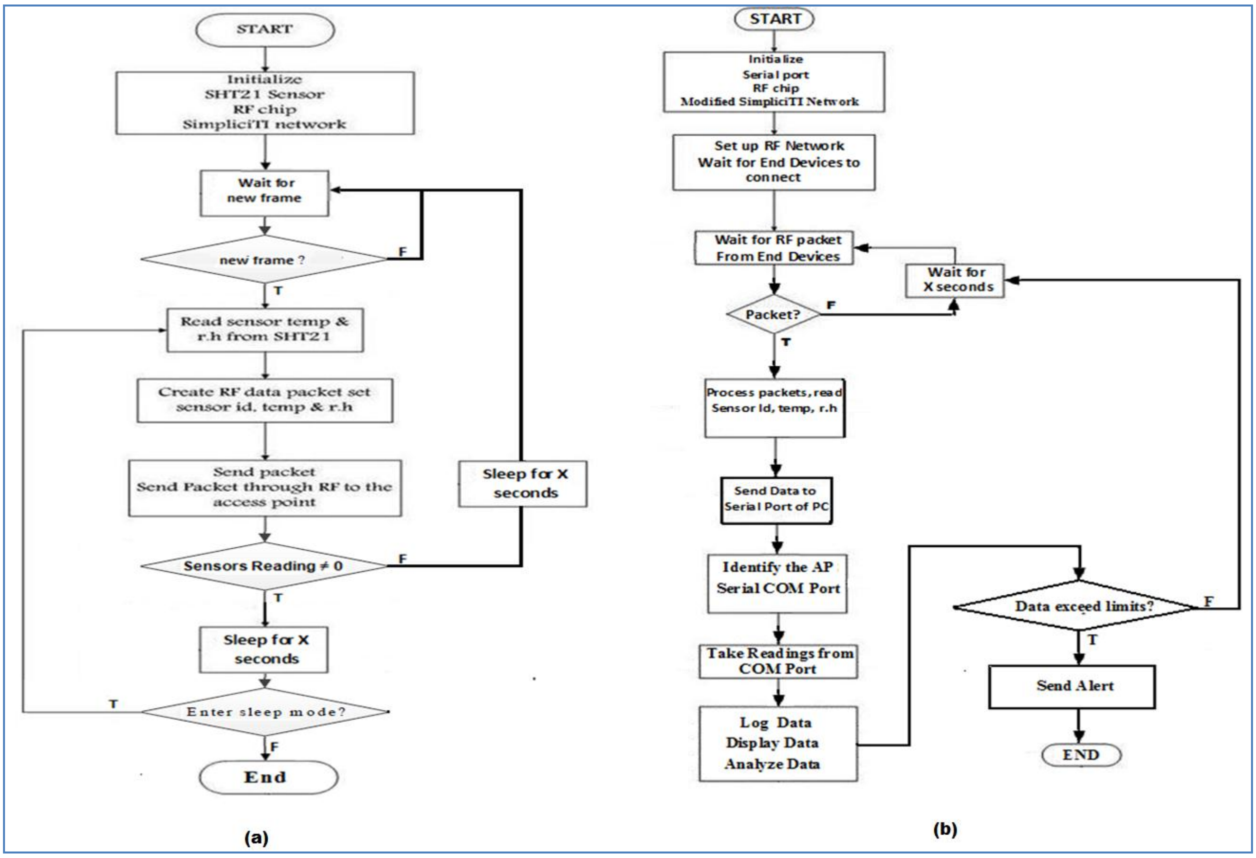

Fig 4: (a) Flowchart of the End Device (b) Flowchart of Network, PC serial port and Alert

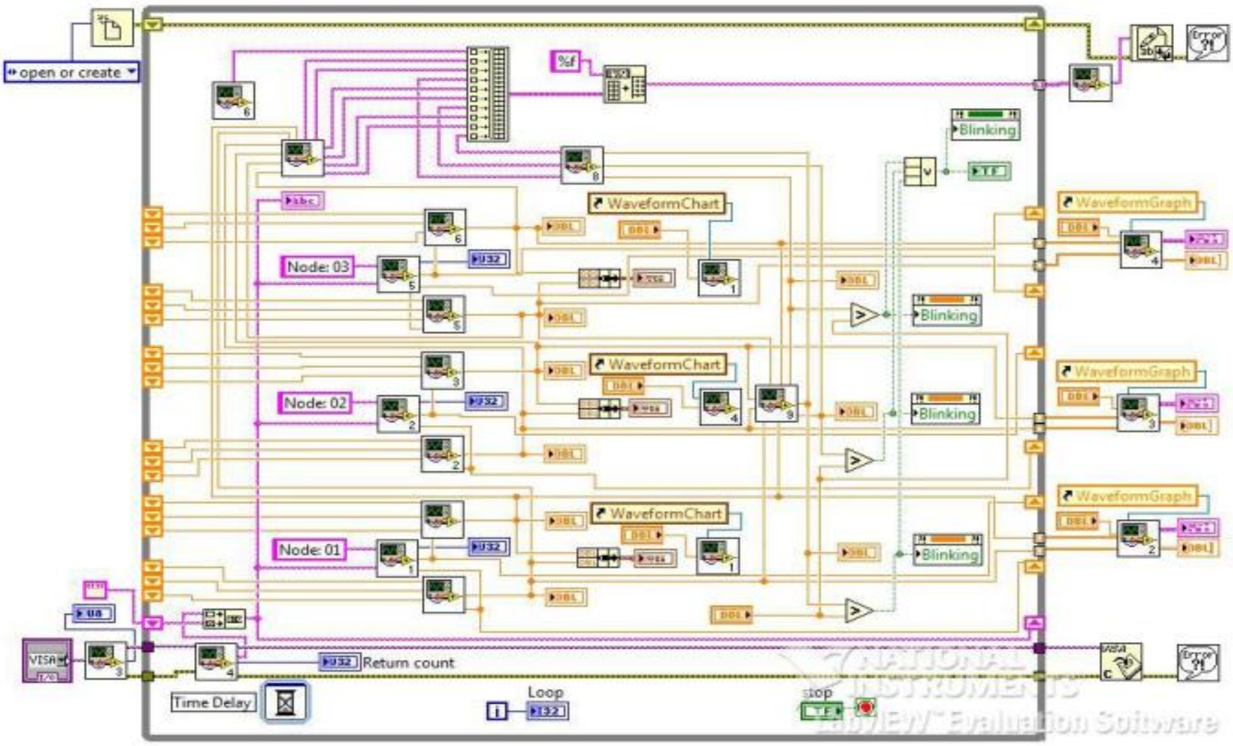

Fig 5: LabVIEW Block Diagram to Receive Data from Sensor Nodes

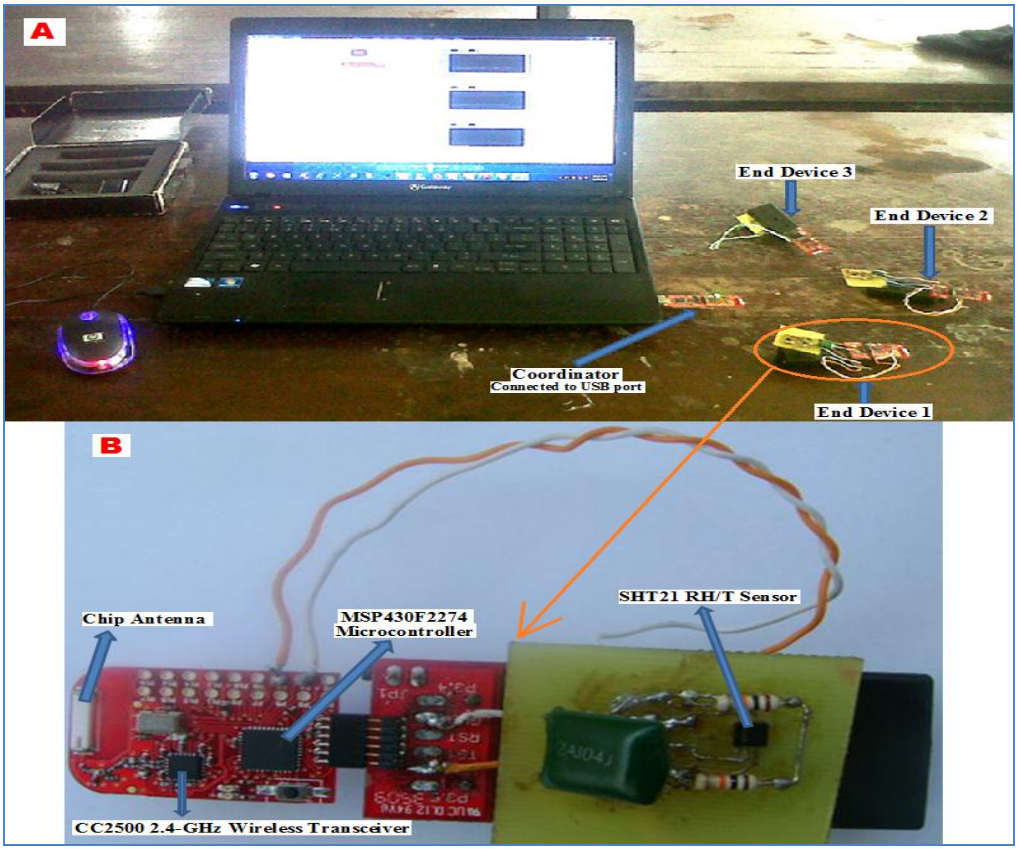

Fig 6: The Wireless Sensor Network Set-up

C. Moisture Content (MC) Determination

a. Measurement

The relationship of the MC with temperature and relative humidity was computed using the modified Oswin Model (Oswin, 1946 and Chen, 2002) as shown in equation 1. The model is a standard acceptable model for shelled maize grain given the coefficients (a = 15.303, b = -0.10184, and c = 3.0358) as indicated in the American Society for Agricultural Engineers (ASAE) Standards D245.5.

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

where: R_h – Relative Humidity (%RH), T – Temperature (^0C), *MC* – Moisture Content (%MC), *a*, *b*, and *c* - constants

b. Evaluation by Oven Drying Method

Oven-drying method is a standard method of evaluating the amount of moisture chemically bound in grains. The MC of the grains (dry basis) is determined by subtracting the oven-dried weight of the sample from the weight of the sample before oven drying as expressed in equation (2).

$$MC = \frac{W_{initial} - W_{oven-dried}}{W_{Oven-dried}} \times 100\% \qquad (2)$$

where: *MC* = Moisture Content
W = Weight of grain sample.

In this study, the maize grain sample examined was the white species found in Southwestern, Nigeria. The freshly harvested sample was weighed initially as W_{inital} = 710 g. The oven, as shown in Fig 7, was warmed to 96.3^{0}C before the grain sample was placed in it. The oven was operated for 96 hrs and the grain sample was removed. Upon removal, the sample was then covered and placed in a desiccator using dry anhydrous calcium sulfate until it got cooled prior to weighing. The sample was then weighed daily using a Mettler PC 2000 electronic balance with an accuracy of 0.01 g. Equilibrium was considered to have been attained when three identical consecutive measurements were obtained. All weighing was performed to the nearest 0.1 g. The weight value at equilibrium was recorded as $W_{oven\text{-}dried}$ = 604.9 g. The MC of the grains was then calculated using equation (2) and compared with the result collected from the WSN system.

Fig 7: Oven-drying of Maize Grain sample

D. Control of MC

On the GUI, the communication (COM) port of the coordinator on the PC was indicated in the 'Device Port'. The 'MC Threshold' control was used to set Threshold parameter MC (Threshold) = 12%MC for safe grain condition. Whenever the MC $\geq$ MC (Threshold) in any of the node, or a node failed; 'ATTENTION' light started blinking and MC display of the particular node of unsafe grain condition also blinked. This alerted the administrator that attention was needed. The administrator was then expected to switch on the drying fan. The fan was only switched off when the condition had been normalized.

III. RESULTS AND DISCUSSION

The result of the characterization of the nodes is as shown in Table I with reference to the standard study by Greenspan (1977) shown in Table II. The results of our study indicate an overall relative agreement with the referenced values. Our data are in good agreement for NaCl and $NaNO_3$, and fairly agree (up to 55%) for KCl and K_2CO_3; but has no agreement with referenced values for K_2SO_4. It is observed that the disagreement for K_2SO_4 was due to the inability of our sensor to operate in the 90 – 100 %RH range. Also, the agreement of the data is very good within the temperature range of 20^0C to 30^0C which corresponded with the grain storage temperature range. Overall, the trends shown by our data for these salts are in good agreement with the literature, demonstrating our node design and method's suitability for studying the relationship between RH and T (for RH < 90%) which are both functions of MC.

Table I: Relative Humidity against Temperature for Salt Aerosols

Temperature (^{0}C)	NaCl	KCl	$NaNO_3$	K_2CO_3	K_2SO_4
5	76.12	86.58	79.23	42.85	80.63
10	76.22	86.25	78.17	42.87	81.47
15	76.03	86.34	77.56	42.91	82.01
20	75.76	85.85	76.03	43.09	83.52
25	75.37	84.59	74.88	43.15	83.87
30	74.91	84.01	73.08	43.16	
35	74.75	81.99	70.95		

Table II: Relative Humidity above Some Saturated Salt Solutions at Various Temperatures (Greenspan, 1977)

Temperature (^{0}C)	NaCl	K_2CO_3	KCl	K_2SO_4
0	75.51 ± 0.34	43.13 ± 0.66	88.61 ± 0.53	98.77 ± 1.1
5	75.65 ± 0.27	43.13 ± 0.50	87.67 ± 0.45	98.48 ± 0.91
10	75.67 ± 0.22	43.14 ± 0.39	86.77 ± 0.39	98.18 ± 0.76
15	75.61 ± 0.18	43.15 ± 0.33	85.92 ± 0.33	97.89 ± 0.63
20	75.47 ± 0.14	43.16 ± 0.33	85.11 ± 0.29	97.59 ± 0.53
25	75.29 ± 0.12	43.16 ± 0.39	84.34 ± 0.26	97.30 ± 0.45
30	75.09 ± 0.11	43.17 ± 0.50	83.62 ± 0.25	97.00 ± 0.40
35	74.87 ± 0.12		82.95 ± 0.25	96.71 ± 0.38

The developed GUI displaying outputs of three nodes is as shown in Fig 8. The stream of data collected from three nodes was as shown in Table III. On the GUI, node 1 indicated MC value of 16.09 %MC; hence the MC display and 'ATTENTION' light blinked. Node 2 indicated a normal condition while Node 3 indicated node failure. The alert for control in this study was real time with reference to the threshold value set.

Table III: Stored Output of Logging Codes with Two Sensor Nodes Connected

Time	Node I			Node II			Node III		
	T^0C	%RH	%MC	T^0C	%RH	%MC	T^0C	%RH	%MC
01/07/2011 12:06	26.05	80.28	16.09	22.68	73.05	11.93	0	0	0
01/07/2011 12:06	26.05	80.28	16.09	22.68	73.05	11.93	0	0	0
01/07/2011 12:06	26.05	80.28	16.09	22.68	73.05	11.93	0	0	0
01/07/2011 12:06	26.04	80.28	16.09	22.66	72.33	11.85	0	0	0
01/07/2011 12:06	26.04	80.28	16.09	22.65	71.97	11.74	0	0	0
01/07/2011 12:07	26.04	80.28	16.09	22.64	71.61	11.64	0	0	0
01/07/2011 12:07	26.04	80.28	16.09	22.63	71.23	11.53	0	0	0
01/07/2011 12:07	26.03	80.28	16.09	22.62	70.75	11.39	0	0	0
01/07/2011 12:07	26.03	80.28	16.09	22.61	70.64	11.36	0	0	0

SN - Sensor Node

The result of oven-drying evaluation of the maize sample showed MC = 17.4%. The MC of the maize grain sample in this study at 20^0C and 78.72%RH was 20.3% dry basis. The result indicated an accuracy of about 87%. It was observed that the result of the oven-dried sample was less than that of our system due to the inability to oven-dry the sample at constant 103^0C continuously for 72hrs as required for best oven-drying method. By inference, at 96.3^0C, the oven heat could not constantly extract away all the water content in the grain sample thereby causing a lower equilibrium MC.

IV. CONCLUSION

This study has developed a good system of wireless sensor network for measuring and controlling moisture content in stored maize grain. The relative agreement of the nodes characterization results with the literature values, the real time control alert, and the accuracy of the evaluation result confirm the viability of our developed system. Meanwhile, our study did not cover effective operation for relative humidity greater than 90%, which is an extreme range beyond useful grain storage. It is meanwhile recommended that an automated drying fan can be incorporated in further research works.

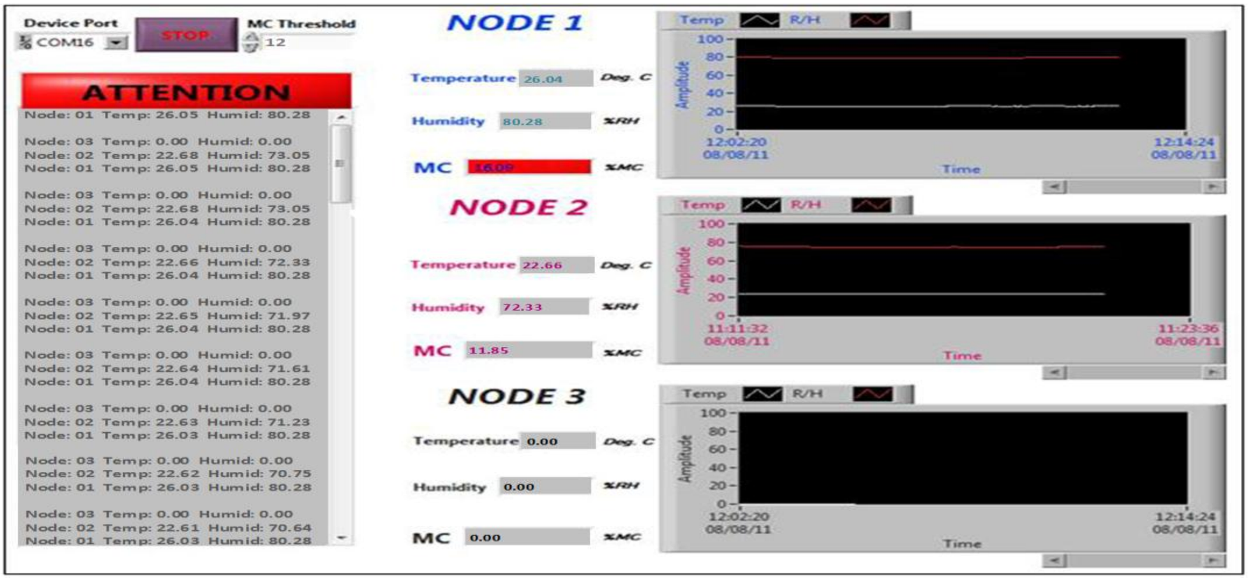

Fig 8: Graphical User Interface

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