Journal of Technological Sciences (JTS) Volume 1, Issue 1, 2022.

Chinhoyi University of Technology
Journal of Technological Sciences
http://journals.cut.ac.zw/index.php/jts

Design and performance assessment of an automatic grain moisture measuring system for use in Zimbabwe

Zvikomborero Hweju[1], Kelvin Chihota[2], Trueman Chiwororo[3], Lee Mafunga[4], Vitalis Munyoka[5] and Prince Nhigo[6]

Department of Mechatronics, School of Engineering Science and Technology, Chinhoyi University of Technology, Chinhoyi, Zimbabwe.

Abstract
Grain moisture content is a key index of grain processing, marketing, and storage security. Hence, its precise determination is of paramount importance. This paper presents the design and performance assessment of an automatic grain moisture measuring system for use in Zimbabwe, based on a microprocessor, photo sensor and moisture sensor. This research has been inspired by the need to eliminate the conventional oven drying based grain moisture content determination technique in use at most Grain Marketing Board (GMB) depots in Zimbabwe. The conventional oven drying technique has the following shortfalls: time-consuming, not suitable for online testing, results in unwarranted wastage of grains due to its destructive nature and the small testing sample is not an accurate representation of the whole grain sample. The performance index that was assessed for the designed system is the system processing time. The average processing time for the system is 3 milli seconds per grain bag. Based on the Mean Absolute Percentage Error (MAPE) the system's grain moisture content determination accuracy is 98.92%. Compared to the conventional oven drying method, the designed system significantly reduces process time and is equally accurate. Hence, the designed system is a suitable replacement for the conventional method in Zimbabwean grain marketing depots.

Key Words: Grain, Moisture Content, Photo Sensor, Moisture Sensor, Storage.

1. Introduction
Moisture content determination and control is a necessity for safe post-harvest storage and processing of grains. The conventional moisture content determination technique in Zimbabwe is the convection oven drying one. This conventional oven drying technique has the following shortcomings: time-consuming, not suitable for online testing, results in unwarranted wastage of grains due to its destructive nature and the small testing sample is not an accurate representation of the whole grain sample. To eliminate the highlighted shortcomings, there has

Corresponding Author. Email address: zhweju@cut.ac.zw

been enthusiastic interest in non-destructive techniques (Kraszewski, 1996; Slima et al., 1999; Kraszewski et al., 1997).

Advances in sensor technology have permitted the quick and accurate online determination of grain moisture content. These moisture content determination techniques are categorized into two groups: direct and indirect techniques (Wang and Wang, 2012). In the direct moisture content determination technique, direct drying and chemical techniques are utilized. Despite this direct method being accurate, it is time consuming and unsuited for online and onsite moisture content determination (Cheng et al., 2000). The indirect methods came about to eliminate the highlighted problems associated with direct methods. Water related physical properties of grains are detected in indirect technique. Such properties include resistance, capacitance, and conductivity.

2. System Working Principle

The designed microcontroller-based system has the following attributes: it detects the presence of a grain bag using a retroreflective sensor, counts the number of grain bags passing through a designated point with the assistance of a counter, detects the moisture content level for each grain bag using a PCE-A-315 sensor and displays the moisture content and destination point of each bag on a 16X2 LCD display. The photo sensor detects an object when it interrupts the light beam between the sensor and reflector. The counter stores the number of times the light beam is interrupted and each time an input pulse is applied to the counter, it increases the number on the counter. The number displayed on the counter corresponds to the number of grain bags that have passed through a point.

The principle of operation of the PCE-A-315 is based on the substantial contrast between the permittivity of dry substances and water at ultra-high frequencies (UHF). The PCE-A-315 sensing component has a ring resonator that has a socket for grain flow. The parameters of the resonator are affected by the interplay between grain flow and resonator field. Automatic correction of measured moisture content is made possible by temperature sensors in the measuring channel. The variation of resonator frequency and amplitude with moisture content is shown by Figure 1. F0 and A0 are the resonator frequency and amplitude respectively when there is nothing in the flow channel. When the channel is filled with grains of a particular moisture content level, the resonator frequency and amplitude decrease to F1 and A1, respectively. A further increase in moisture content will result in resonant frequency and amplitude values of F2 and A2, respectively. Concurrent measurement of resonant frequency and amplitude permits determining moisture content separately of grain density.

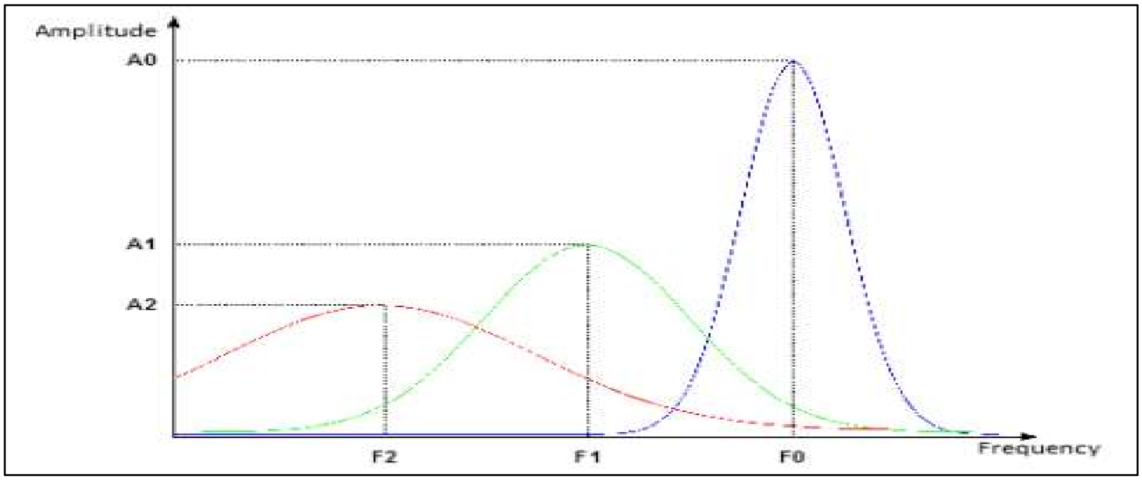

Figure 1: PCE-A-315 Variation of Frequency and Amplitude with Moisture Content

3. Design of the System

The proposed system is a multi-disciplinary system, that is, it abstracts knowledge from many engineering disciplines. Therefore, a methodology that supports multi-disciplinary approach has been utilized. The VDI model has been used in the design of the moisture content determination system. Table 1 shows the formulation of final requirements from narrative requirements.

Table 1: Narrative and F Requirements

Narrative Requirements	**Abbreviation**	**Final Requirements**
The system must sense moisture content.	R1	Acceptable moisture content for safe storage: ≤ 13 %.
The system must count grain bags delivered.	R2	Grain bags counting: increment count for each detected grain bag.
The system must transfer grain bags to the storage silos or driers depending on moisture content.	R3	Moisture content >13%: transfer to driers. Moisture content ≤ 13%: transfer to storage silos.
The system must have efficient energy consumption.	R4	Operating Voltage: 12±2 V for control system and 380 V for driving system.
The system must be easy to maintain.	R5	Simple maintenance
The system must be environmentally friendly.	R6	Environmentally friendly materials must be used.

The system is controlled by the microcontroller as indicated by the flow chart in Figure 2.

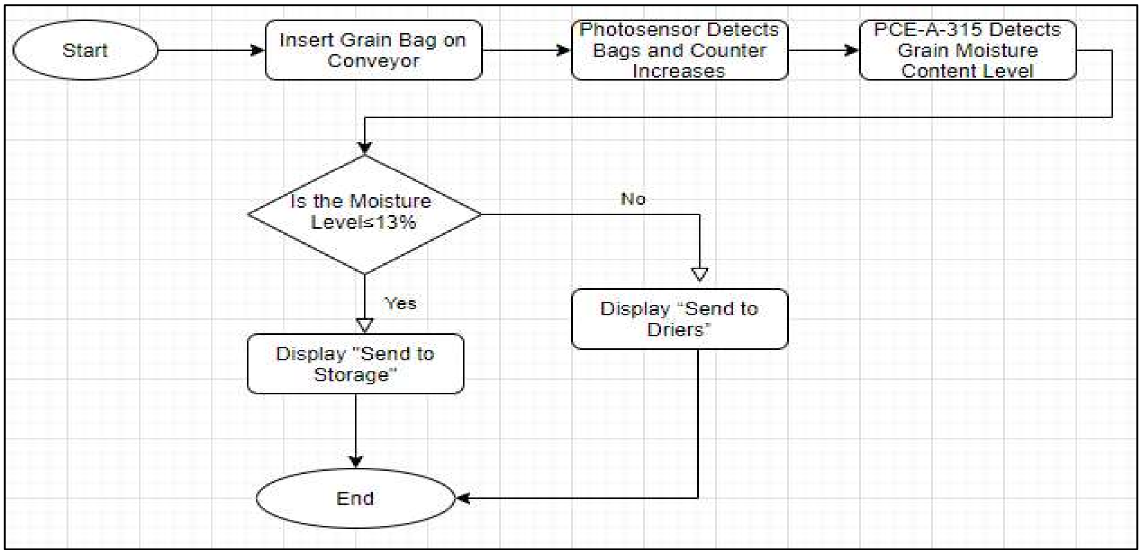

Figure 2: System Process Flow Chart

Figure 3 illustrates the electronic circuit of the moisture content detection and decision making of the system. The system is run by a DC voltage with a value of 12V and current of 5A. The system uses an Arduino Uno with 14 digital input/output pins, 6 analog inputs and a 16 MHz ceramic resonator as the microcontroller board. This microcontroller board is implemented in conjunction with a ULN2003 stepper motor driver which provides an interface between the microcontroller and the stepper motor.

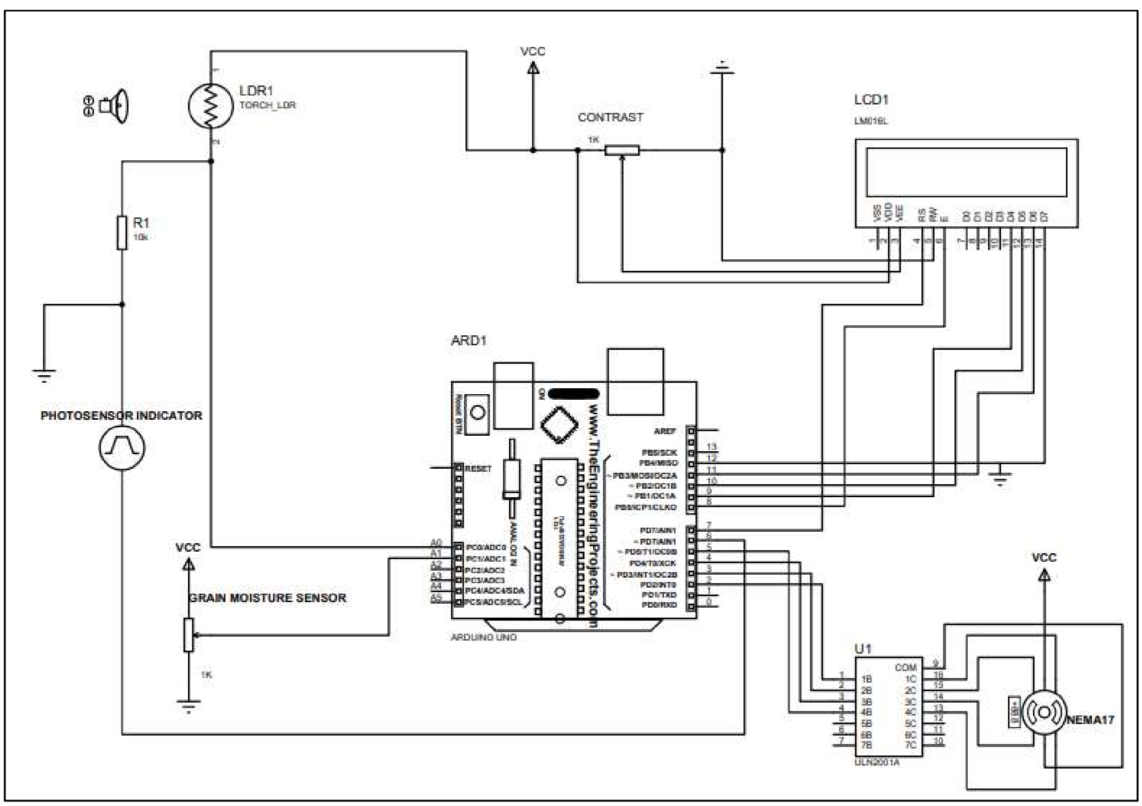

Figure 3: Schematic Diagram for the Moisture Control Electronic Circuit

The designed mechanical system is presented in Figure 4. The model has been produced with solid works. The model shows the relative positioning of the sensors, conveyor belt and motor. Both the photo sensor and the moisture content detection sensor are mounted onto the sensors post.

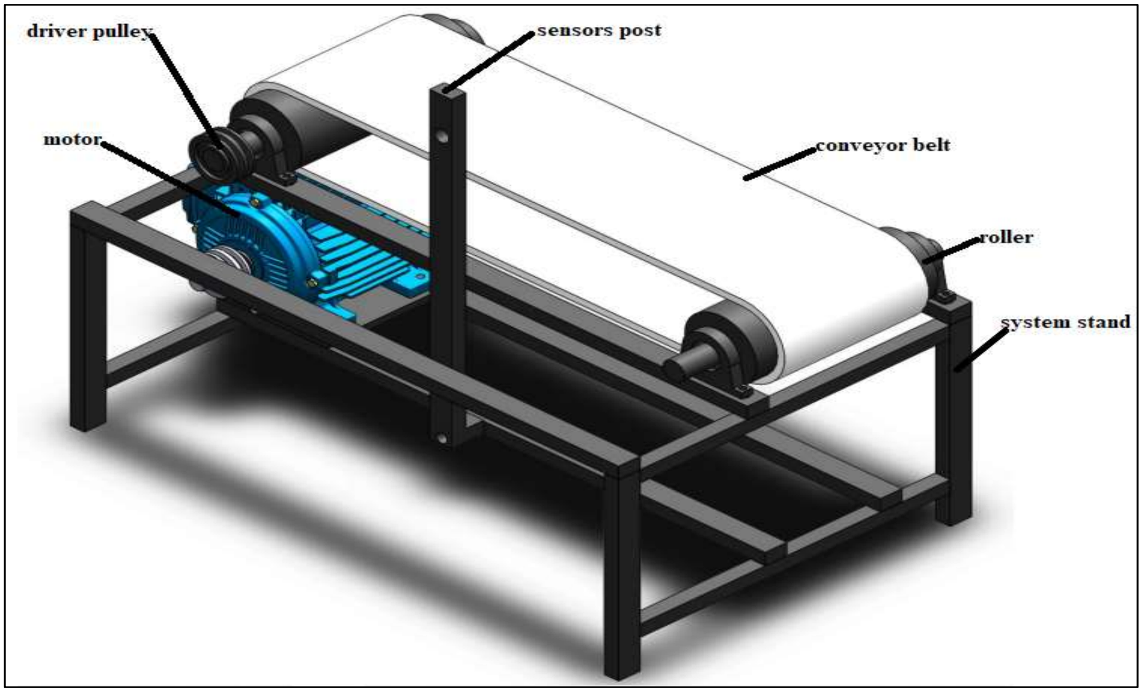

Figure 4: System Mechanical Structure

A snapshot of the assembled model is presented by Figure 5.

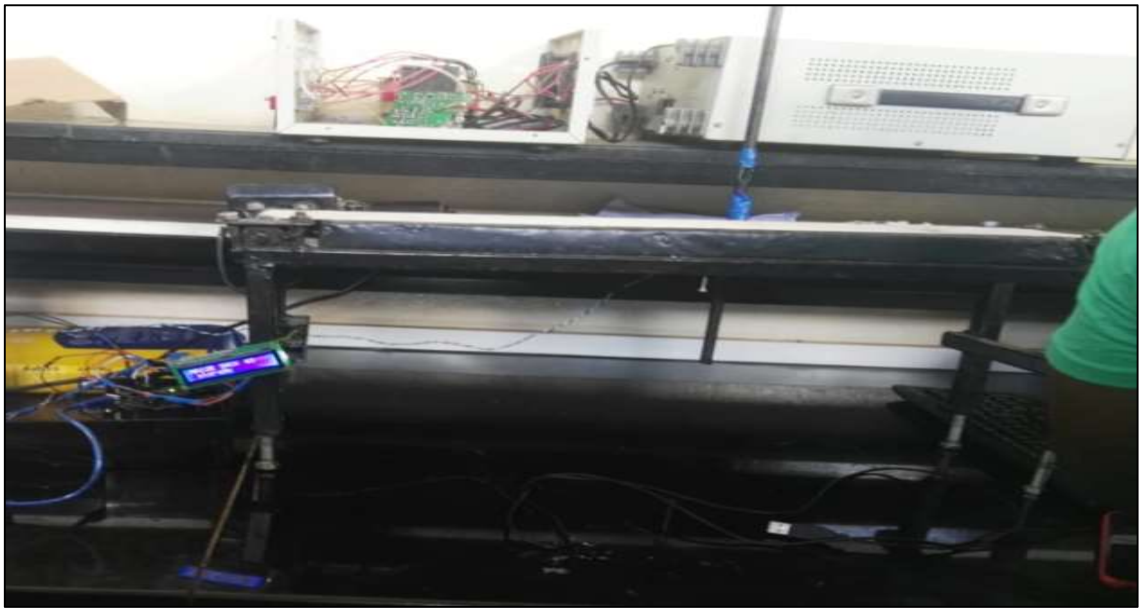

Figure 5: Moisture Detection System During Assembly

4. Results and Discussion

The online determined grain moisture content values have been tabulated against the corresponding oven drying method results (Table 2). The mean absolute percentage error of the results obtained by the designed system are tabulated as well. A paired t-test is used to determine whether the difference between the two sets of results is significant (Table 3). Equation 1 gives the MAPE:

$$MAPE = \left(\frac{1}{n}\sum_{i=1}^{n}\left|\frac{M_{a,i}-M_{a,i}^{P}}{M_{a,i}}\right| \times 100\right) \qquad (1)$$

Table 2: Grain Moisture Content Results

Oven-Based Moisture Content (%)	**Online-Based Moisture Content (%)**	**MAPE (%)**
13.5	13.2	2.22
13.1	13.0	0.76
12.9	13.1	1.55
13.7	13.5	1.46
14.0	14.1	0.71
13.9	13.9	0.00
12.8	12.7	0.78
14.2	14.0	1.41
13.0	13.1	0.77
13.4	13.2	1.49
12.4	12.3	0.81
Mean Absolute Percentage Error		**1.09**
System Accuracy		**98.91**

Table 3: Paired t-test Moisture Content Values

Attribute	Value
Oven-Based Moisture Content Mean	13.355
Online-Based Moisture Content Mean	13.282
Sample Size (n)	11
Oven-Based Moisture Content Standard Deviation	0.565
Online-Based Moisture Content Standard Deviation	0.555
Null Hypothesis	H_0: μ_D=0
Alternative Hypothesis	H_0: μ_D ≠0
Significance level	$\alpha = 0.05$
Degrees of freedom (DoF)	10
Critical value (t_c)	2.228
t-statistic	1.551

Since it is observed that $|t| = 1.551 \leq t_c = 2.228$, it is then concluded that the null hypothesis is not rejected. Using the P-value approach: The p-value is $p = 0.1519$, and since $p = 0.1519 \geq 0.05$, it is concluded that the null hypothesis is not rejected. Therefore, there is not enough evidence to claim that the population mean μ_1 is different from μ_2, at the 0.05 significance level.

4. Conclusion and Recommendations

In this study, a novel microcontroller-based grain moisture content detection system has been designed. In comparison with the conventional oven drying method in use at most grain marketing depots in Zimbabwe, this new method will only reduce the detection time, improve accuracy and is capable of online detection. The designed system modularity results in easiness of troubleshooting and maintenance. The system is also suitable for teaching the concepts of industrial automation to students. The designed system accuracy of 98.91% is an exhibition of the systems reliability. The paired t-test rest signifies the lack of sufficient evidence to reject the hypothesis that the means of the two samples are the same.

For future work, a system is to be developed that integrates grain weighing and moisture assessment. Since the design scope was limited to moisture level determination and specifying the intended destination of the grain bags, there is need for designing a grain conveyancing system to the intended destination in future.

References

Cheng, W. D. Bai, X. Y. and Wang, X. Y. (2000) An online measurement and monitoring system of grain moisture during drying process. *Transactions of the Chinese Society of Agricultural Machinery*, Vol. 31, pp. 53-55.

Kraszewski, A. (1996) Microwave aquametry: Electromagnetic wave interaction with water-containing materials. New York: IEEE Press.

Kraszewski, A. W. Trabelsi, S. and Nelson, S. O. (1997) Moisture content determination in grain by measuring microwave parameters. *Measurement Science and Technology*, vol. 8.

Slima, M. B. Morawski, R. Z. Kraszewski, A. W Barwicz, A. and Nelson, S. O. (1999) Calibration of a microwave system for measuring grain moisture content. *IEEE Transactions on Instrumentation and Measurement*, Vol. 48, pp. 778 - 783.

Wang, W. C. and Wang, L. (2012) Design of Moisture Content Detection System. Physics Procedia, Vol. 33, pp. 1408-1411.