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Development of Optimized System for Measurement and Detection of Moisture Level in Grains.

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Abstract: Moisture content is a key factor affecting the quality, shelf life, and market value of grains. Accurate detection is essential for proper storage, processing, and overall post-harvest management. This study reviews both traditional and modern techniques for measuring moisture content. While methods like oven drying are reliable, they are time-consuming and unsuitable for real-time use. In contrast, advanced techniques such as capacitance, microwave, and near-infrared (NIR) spectroscopy provide faster, more accurate, and often non-destructive alternatives.

The study discusses the working principles, advantages, and limitations of each method, focusing on accuracy, efficiency, and cost. Experimental results highlight the effectiveness of modern, non-invasive techniques in delivering rapid and precise moisture readings without damaging the grain. These technologies enable better decision-making in storage and processing, helping reduce post-harvest losses, maintain grain quality, and support food security.

Keywords: USB to TTL UART Serial Converter, ADS1115, MS51FB9AE, etc.

I. INTRODUCTION

Grain moisture measurement plays a vital role in ensuring quality, safety, and fair trade in both local and international markets. High moisture content in freshly harvested grains makes them prone to spoilage, microbial growth, and pest infestations, rendering them unsuitable for long-term storage. Drying not only enhances shelf life but also reduces weight, making transportation more economical. From a trade perspective, selling wet grains means customers pay for water weight, while drying adds cost and effort for producers, thereby increasing the market value of dried grains. Accurate moisture assessment is essential for preserving grain nutritional value and sensory characteristics. Traditional methods such as oven drying, though reliable, are often time-consuming and labour-intensive. Recent technological advancements have introduced modern, non-destructive techniques such as near-infrared spectroscopy (NIRS), microwave resonance, and capacitance-based sensors. These methods offer faster, more efficient moisture detection with minimal sample preparation, making them suitable for real-time and large-scale applications.

In the global food supply chain, poor drying and storage practices can lead to substantial post-harvest losses and economic impacts. Moisture levels also influence processing quality in industries like flour milling and biofuel production, where precise control is critical for consistency and energy efficiency. Moreover, environmental factors like temperature and humidity affect moisture migration within stored grains, potentially leading to clumping, nutrient degradation, and compromised processing properties.

To address these challenges, advanced storage solutions such as aerated silos, hermetic containers, and IoT-based real-time monitoring systems are being adopted. These innovations, along with modern moisture detection technologies, allow for better decision-making in grain handling, reducing spoilage and improving efficiency.

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This study aims to explore the impact of moisture content on grain quality and industrial applications while highlighting state-of-the-art measurement techniques and strategies for sustainable moisture management across the agricultural supply chain.

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II. RELATED WORK

The measurement of grain moisture content has evolved significantly over time. Traditional methods, such as the oven-drying technique and Karl Fischer titration, have been widely used due to their accuracy [1]. However, these methods are often labour-intensive, time-consuming, and unsuitable for large-scale, real-time monitoring.

Numerous studies have examined how excessive moisture in stored grains contributes to mould growth, biochemical deterioration, and pest infestations. Investigated how environmental factors such as temperature and humidity influence moisture migration within stored grains, leading to caking and germination losses [2]. Similarly, research by analysed the biochemical changes in high-moisture grains, showing that increased moisture accelerates.

To overcome these limitations, researchers have explored modern moisture detection methods, including near-infrared spectroscopy (NIRS), microwave resonance, and capacitance-based sensors. NIRS, for example, provides rapid and non-destructive moisture analysis based on the absorption of infrared light at specific wavelengths. Microwave-based sensing techniques leverage the interaction between microwaves and water molecules to estimate moisture content with high precision, even in bulk storage conditions. Impedance-based sensors, which measure changes in electrical conductivity relative to moisture levels, have also gained attention for their accuracy and efficiency' [3].

Storage conditions play a crucial role in maintaining the optimal moisture content of grains. Various studies have explored advanced storage solutions to prevent moisture-related spoilage. Suggested the use of aerated silos and hermetic storage techniques to minimize moisture absorption and fungal growth. Additionally, controlled-environment storage systems, which regulate temperature and humidity, have been found effective in preserving grain quality over extended periods.

Beyond its impact on quality and storage, grain moisture content has significant economic implications. Research has shown that high-moisture grains lead to increased transportation costs and weight discrepancies in trade [5]. Additionally, the milling industry requires precise moisture control to maintain efficiency and consistency in flour production. The biofuel sector is also affected, as excessive moisture in feedstock reduces combustion efficiency and energy output.

III. METHODOLOGY

Working Principle of the Resistive Moisture Detection System:
The resistive moisture detection system operates based on the principle of measuring the dielectric and resistive properties of grains through the use of two electrode rods. These rods serve as conductive probes that detect variations in electrical resistance, which correlate directly with the moisture content in the grain. As moisture levels in the grain increase, the dielectric constant and electrical conductivity also change. These analog signals are collected and sent to the ADS1115, a high-resolution 16-bit analog-to-digital converter (ADC). This ADC is responsible for accurately digitizing the analog voltage signals from the electrodes into digital values suitable for processing.

The digital data is then transmitted to the MS51FB9AE microcontroller, a compact and efficient controller from Nuvoton's 8051 series. This microcontroller acts as the brain of the system—it filters out electrical noise, applies calibration algorithms, and computes the moisture content using a pre-determined equation based on empirical data.

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Following the processing, the microcontroller sends the final results via a USB-to-TTL UART Serial Converter, which allows seamless communication with external devices such as a computer or mobile application for real-time monitoring and display.

❖ Block Diagram

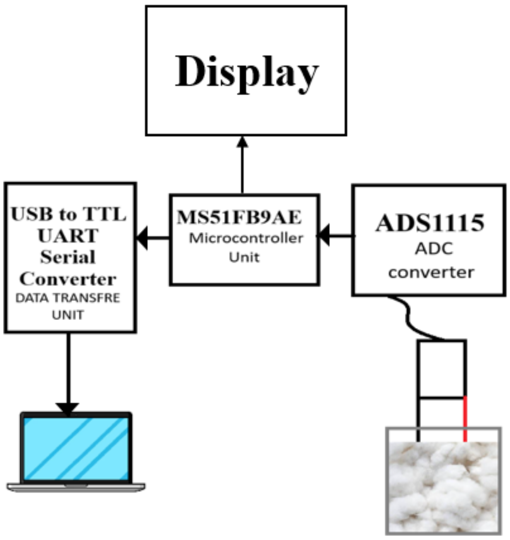

Fig. 1. Block Diagram of system

❖ **Data Collection and Signal Processing**

The electrode rods are inserted into the grain sample, where they generate a weak electrical field.
Due to the varying moisture content, the grains cause fluctuations in the electrical resistance and voltage between the rods.
These variations are captured by the ADS1115 ADC, which converts them into high-resolution digital values.
The MS51FB9AE microcontroller receives these values, performs signal filtering to remove electrical noise, and then uses calibrated mathematical models to calculate accurate moisture percentages.

❖ **Algorithm Development**

To ensure precise measurement and accommodate different types of grains, the system relies on a robust algorithm:

1. **Calibration** is done using pre-recorded reference data for various grain types to enhance measurement reliability.
2. **Regression Models**: Linear and polynomial regression models are applied to convert raw ADC data into meaningful moisture values.
3. **Error Correction**: The system includes dynamic correction algorithms that consider environmental factors and grain type differences to improve the system's adaptability and accuracy.

❖ **System Integration**

The USB to TTL UART Serial Converter acts as a communication bridge between the microcontroller and an external display or PC, enabling fast and real-time data transfer.
A graphical user interface (GUI), such as XCTU or custom PC/mobile software, presents the moisture readings in an intuitive format, allowing users to interpret results without requiring technical expertise.

❖ **Testing and Validation**

The system undergoes extensive validation by comparing its moisture readings with industry-standard moisture meters.
Performance is tested across a range of grain types—such as rice, wheat, and maize—under different humidity conditions to ensure consistent accuracy.
Calibration refinements are made based on field tests to enhance the system's reliability and commercial viability.

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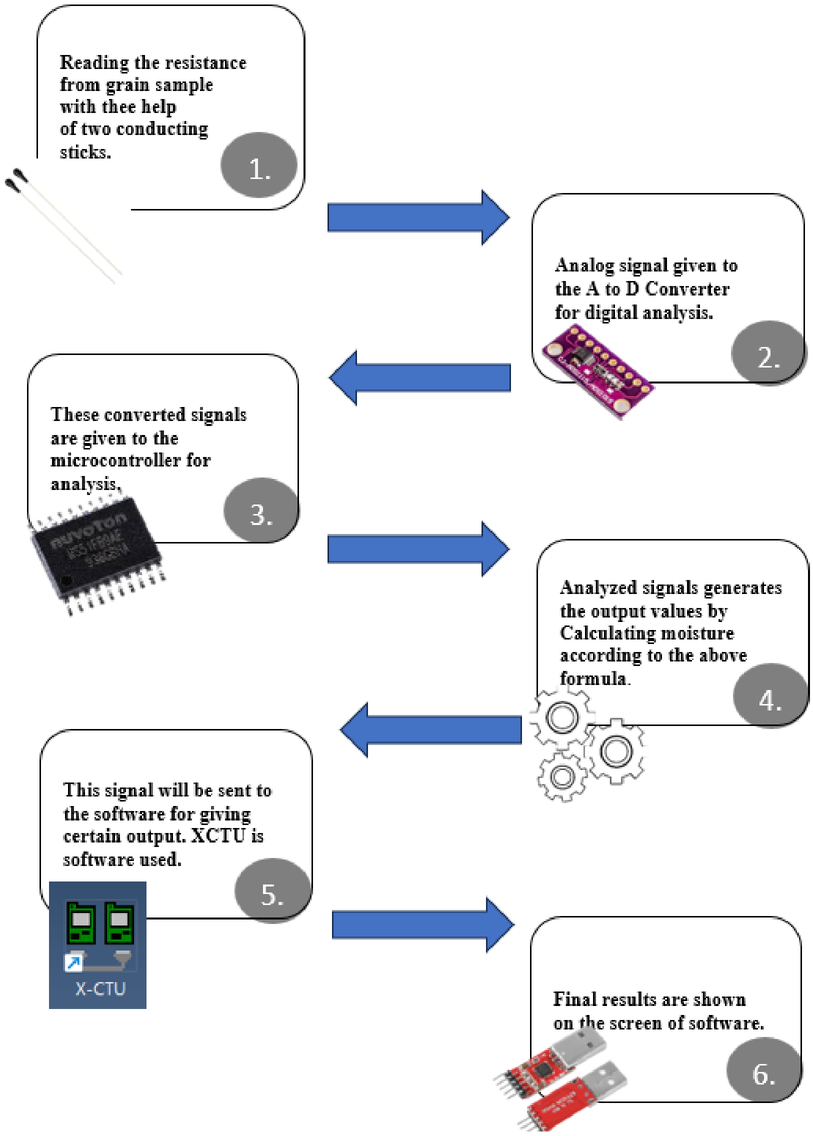

❖ Deployment and User Operation

To operate the device, the user simply inserts the electrode rods into the grain sample and connects the system to a PC or mobile interface via USB-TTL. The microcontroller instantly processes the readings and transmits the moisture data for display. The real-time monitoring allows users to assess grain quality on-site. Additionally, the system's software can be updated periodically to incorporate improved algorithms and calibration data, further increasing accuracy over time.

❖ Mathematical Formula for Moisture Calculation

In resistive moisture detection systems, moisture content is typically derived from the resistivity of the grain material using an empirical formula:

$$\boxed{\rho = A \cdot (M)^B}$$

Where:

- **ρ** = Resistivity of the grain sample (in ohm-meters)
- **M** = Moisture content (expressed in percentage or fraction)
- **A and B** = Empirical constants obtained through experimental calibration specific to the type of grain

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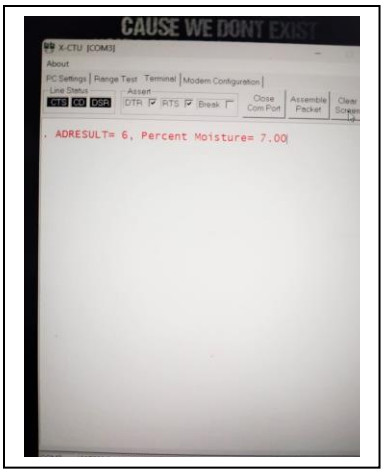
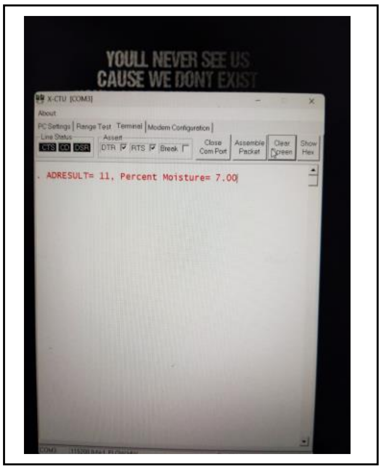
This formula models the nonlinear relationship between moisture content and electrical resistivity and allows for accurate conversion during signal processing.

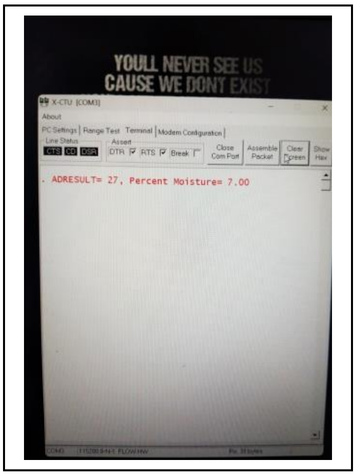
❖ **Sensor-Less Advantage**

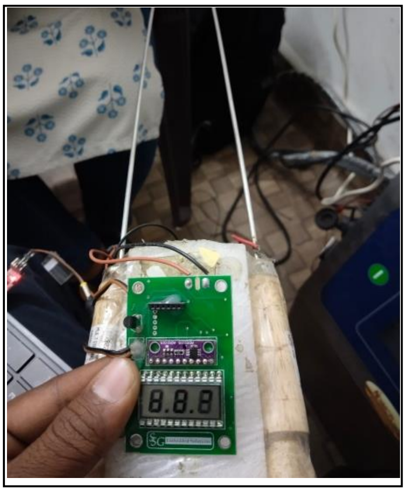
Notably, this system can be considered “sensor-less” in the traditional sense, as it does not rely on pre-packaged moisture sensors. Instead, it utilizes simple conducting rods and signal-processing techniques, thereby reducing hardware costs while still achieving high accuracy through software and calibration. This makes the system not only cost-effective but also easier to maintain and adapt across different grain types.

IV. EXPERIMENTAL RESULTS AND DISCUSSION









These are some images of our project showcasing the system in operation. The system is actively measuring and displaying the moisture content from various grain samples. All the results shown are calculated and analysed by the proposed sensor-less resistive moisture detection system. The system successfully demonstrates its capability to provide accurate and real-time moisture readings. Moreover, one of the key achievements of this project is that the entire system has been developed at a significantly lower cost compared to conventional commercial moisture meters, making it an affordable and efficient solution for farmers and grain handlers.

❖ **Advantages of this system: -**

Accuracy: The moisture readings obtained from the system will closely match those from standard reference devices (e.g., oven-drying method), with an expected accuracy range of ±1% to ±2%.

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Fast Response: The system will provide instant moisture readings (within seconds), making it suitable for real-time monitoring during grain storage or processing.
Cost Efficiency: As the system eliminates the need for expensive moisture sensors, the overall cost of production is significantly lower than commercial devices.
Non-Destructive Testing: The method will not harm or alter the physical quality of the grains, making it ideal for bulk testing.
Versatility: The system is expected to work effectively across a wide range of grain types and moisture levels.
Low Power Consumption: Due to the use of a simple microcontroller and minimal hardware, the system will operate efficiently with low power input.
PC-Based Visualization: With the help of XCTU or a custom interface, users will be able to monitor moisture values visually and export the data for further analysis.
Repeatability and Reliability: Repeated measurements under similar conditions will yield consistent results, ensuring reliability in practical use.
Environmental Adaptability: The system will be able to function in various environmental conditions (temperature, humidity) with minimal recalibration.
User-Friendly Operation: With simple probe insertion and USB connection, even non-technical users will be able to operate the system easily.

V. CONCLUSION

The implementation of a resistive moisture measurement system for grains presents an efficient, accurate, and cost-effective approach to determining grain moisture content. By employing conductive rods as probes, the system effectively detects the electrical properties of the grains, which fluctuate based on moisture levels. The integration of the ADS1115 analog-to-digital converter (ADC) ensures high-precision conversion of analog signals into digital data, while the MS51FB9AE microcontroller processes this information using predefined calibration formulas to accurately calculate moisture content.

A USB-to-TTL UART Serial Converter enables seamless communication between the microcontroller and a personal computer (PC), where software such as XCTU is used to interpret and display real-time moisture readings.
This configuration not only enhances measurement accuracy but also supports fast and real-time monitoring, making it highly applicable for various agricultural and post-harvest operations.

Overall, this method offers a non-destructive, reliable, and scalable solution for moisture detection in grains, assisting farmers, traders, and agricultural industries in improving grain quality, optimizing storage conditions, and minimizing post-harvest losses. Future advancements may include refining calibration algorithms, incorporating IoT-based monitoring systems, and enhancing compatibility with a wider variety of grain types to further improve the system's performance and usability.

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