Smart Wool Quality Checker Using ESP32

Author

Prof. S.M.Pange | Kanishka Mali | Shrenika Hajare | Hrushikesh Pawar

Department of Electronics and Telecommunication Engineering Jaywantrao Sawant College of Engineering, Pune, India

Abstract –

Wool quality evaluation is an important factor that directly influences its market price and usability in the textile industry. Conventional grading methods mainly depend on manual inspection, which can be inconsistent, time-consuming, and dependent on human judgment. To overcome these limitations, this paper presents a portable and intelligent wool quality checking system built using an ESP32 microcontroller with IoT integration. The system is capable of analyzing key parameters such as fiber thickness, moisture level, color characteristics, weight, and surrounding environmental conditions using a combination of sensors and imaging components.

The acquired data is processed within the device and then transmitted to a cloud platform for real-time monitoring and storage. This approach allows farmers, buyers, and manufacturers to remotely access reliable and standardized wool quality reports. The proposed solution enhances transparency, minimizes reliance on laboratory-based testing, and supports better decision-making throughout the supply chain. The developed prototype shows stable performance, low energy consumption, and affordability, making it practical for real-world agricultural use.

Keywords — ***ESP32, Wool Quality, Embedded System, Sensor Integration, Supply Chain Monitoring , Smart Agriculture.***

I. INTRODUCTION

Wool is a widely used natural fiber that plays a significant role in the textile industry. Its quality has a direct impact on both its market value and its suitability for various applications. Traditionally, wool grading is carried out manually by experienced professionals, which makes the process subjective and sometimes inaccurate due to human involvement.

In many rural areas, farmers do not have access to advanced laboratory facilities for proper wool testing. This leads to a mismatch between the actual quality of wool and the price they receive, often putting farmers at a disadvantage. Hence, there is a strong need for a compact and intelligent system that can evaluate wool quality directly at the source.

With recent developments in embedded systems and IoT technologies, it has become possible to design smart devices that can perform real-time monitoring and data communication. The proposed system utilizes an ESP32-based platform along with multiple sensors and a camera module to deliver an automated, reliable, and accurate solution for wool quality assessment.

II. LITERATURE SURVEY

Recent advancements in IoT-based monitoring systems have significantly improved quality analysis, transparency, and operational efficiency in agricultural supply chains. As discussed in [1], the combination of Artificial Intelligence and IoT in the wool sector enables automated grading, improved decision-making, and live data monitoring. Another study [2] presented a sensor-driven waste management platform with cloud support, showing how remote monitoring systems can increase efficiency. Research in [3] also demonstrated that microcontroller-based IoT systems with data logging and time stamping help create reliable and traceable monitoring solutions.

Over the past few years, the integration of IoT devices, wireless sensors, cloud platforms, and automation technologies has modernized many traditional industries. Several researchers have focused on smart sensing, quality evaluation, environmental monitoring, and scalable IoT frameworks. This literature survey highlights notable contributions and identifies research gaps that inspired the development of the proposed Smart Wool Quality Checker System.

[1] Transforming the Wool Supply Chain with AI for a Data-Driven Approach to Quality Control (2025):
This research explored the application of Artificial Intelligence and IoT for improving wool grading and quality management. It focused on smart decision-making and better visibility in the supply chain. However, the study mainly emphasized software intelligence rather than portable field devices for direct farmer use.

[2] IoT-Based Smart Waste Management System: India Prospective (2019):
This work used ultrasonic and gas sensors with GSM/GPRS communication and a web dashboard for live waste monitoring. While intended for waste management, its sensor-based monitoring and remote dashboard concepts are useful for wool storage and moisture tracking systems.

[3] Low-Cost Energy Efficient Smart Security System with Information Stamping for IoT Networks (2018):
The authors developed a low-cost IoT security model using Raspberry Pi/ESP controllers with cloud storage and event logging. The project showed the value of secure monitoring and timestamp-based records, which are relevant to the proposed wool quality checker using ESP32 and Wi-Fi connectivity.

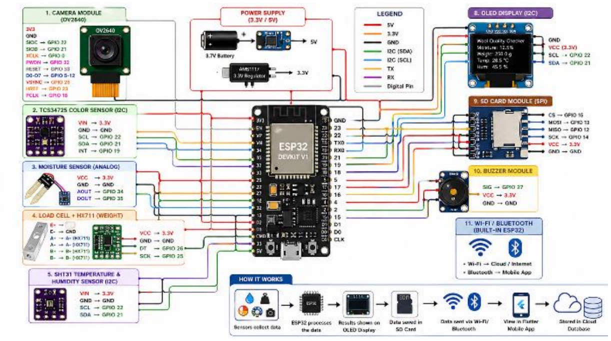
[4] Smart Agriculture System Using IoT (2020):
This study designed an agricultural monitoring system using DHT sensors, soil moisture sensors, and ESP modules. It successfully monitored environmental conditions in real time. Similar methods can be applied to track temperature, humidity, and moisture levels affecting wool quality.

[5] Native Web Communication Protocols and Their Effects on the Performance of Web Services and Systems (2016):
This paper analyzed modern communication protocols such as HTTP/2 and SPDY for faster and more efficient data exchange. The results are valuable for designing responsive mobile applications and cloud services for wool quality data transfer.

[6] NFV Enabled IoT Architecture for an Operating Room Environment (2018):
This research proposed a scalable IoT architecture using NFV and REST-based services. Although developed for healthcare environments, the same concept can support future large-scale deployment of wool monitoring systems across farms, warehouses, and industries.

Although many studies have contributed to IoT monitoring and automation, certain limitations still exist, such as the absence of portable wool testing devices, dependence on manual grading, delayed reporting, and lack of transparent digital records. The proposed Smart Wool Quality Checker System addresses these problems by combining ESP32, multiple sensors, image capture, Flutter mobile application, cloud integration, and wireless communication into a practical, low-cost, and portable solution..

III. SYSTEM DESIGN AND METHODOLOGY



The proposed wool quality checker is developed as a portable and user-friendly embedded system that enables farmers to evaluate wool quality directly at the source. The design emphasizes simplicity, reliability, and low power consumption so that it can be easily used in rural and field environments. By combining sensing, processing, and communication capabilities into a single device, the system eliminates the need for complex laboratory testing and allows instant analysis.

The overall system is structured into different functional units, namely sensing, processing, storage, and communication modules. The sensing unit includes multiple sensors such as a load cell to measure weight, a moisture sensor to detect water content, a color sensor to analyze wool appearance, and a temperaturehumidity sensor to monitor environmental conditions. A camera module is also included to capture detailed images of wool fibers. All these components are interfaced with the ESP32 microcontroller, which acts as the main control unit.

When the device is in operation, the user places a wool sample inside the measurement area, and the system begins collecting data from all sensors. The weight of the sample is recorded using the load cell, while the moisture sensor evaluates the level of moisture present. The color sensor captures RGB values to assess the visual quality and identify possible impurities. At the same time, environmental parameters such as temperature and humidity are recorded, as they influence wool characteristics.

Along with sensor readings, the camera captures a focused image of the wool sample under controlled lighting conditions. This image is used to observe fiber structure and detect visible contaminants. The ESP32 performs basic processing tasks such as filtering sensor noise, averaging values, and preparing the collected data for storage and transmission. This local processing helps reduce system delay and improves overall efficiency.

Once the data is processed, it is organized into a structured format that includes all measured parameters along with time-related information. The system stores this data in local memory using an SD card, ensuring that no information is lost even when internet connectivity is not available. This makes the device reliable for use in remote locations where continuous network access may not be possible.

Whenever a network connection becomes available, the stored data is transmitted to a cloud platform using wireless communication. The cloud system allows users such as farmers, buyers, and manufacturers to access detailed wool quality reports from any location. This complete process ensures accurate data collection, secure storage, and easy accessibility, ultimately improving transparency and efficiency in the wool supply chain.

A. Microcontroller (ESP32)

Serves as the main control unit of the system. It is responsible for collecting data from all connected sensors, performing basic processing, and managing wireless communication through Wi-Fi and Bluetooth. It also handles data storage and transmission to the cloud platform for further analysis.

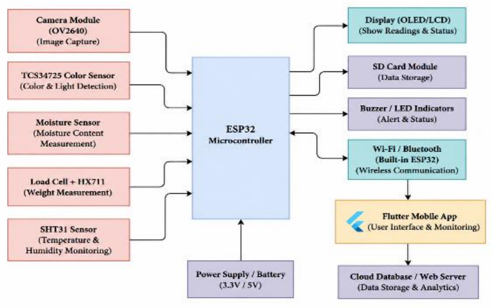


Fig. 1. Block diagram of ESP32-Based Wool Quality Checker System

Hardware Box (ESP32 Device): The core portable unit given to farmers. It contains:

Sensing Subsystem: Includes the OV2640 Camera with optical lens, TCS34725 Color Sensor, Load Cell with HX711 amplifier, Moisture Sensor, and SHT31 ambient temperature/humidity sensor.

Processing Unit: ESP32-WROOM/WROVER microcontroller.

User Interface: Simple buttons, status LEDs, potentially a small LCD.

Storage: SD card module or SPI flash for offline data logging.

Connectivity: Built-in Wi-Fi and Bluetooth. Optional LoRa/NB-IoT.

Support Components: RTC (DS3231) for timestamping, LED illumination ring, Battery system (Li-ion, charger, protection).

Farmer UI: A smartphone application (Android/iOS or webbased) that connects to the hardware box (primarily via Bluetooth if Wi-Fi is unavailable) to trigger measurements, view results, manage uploads, and potentially access other farm-related services.

Backend / API: A cloud-based server application that:

Receives and validates data uploads from the hardware box or mobile app.

Stores measurement data, quality reports, and images securely in a database.

Exposes RESTful APIs for other system components.

Implements business logic for grading, user management, etc.

Manufacturer / Buyer Portal: A web-based dashboard allowing registered buyers to search, filter, and view wool quality reports, request samples, and potentially initiate purchases.

Transport & Warehouse Module: Software components (likely integrated into the Backend and potentially separate mobile apps for drivers/staff) to log shipment details, track lots using IDs (e.g., QR codes), record storage conditions, and manage the chain of custody.

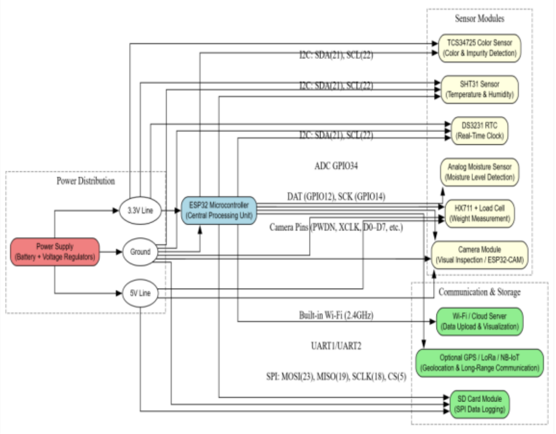


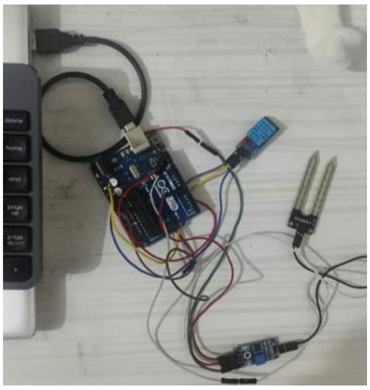
Fig. 2. Connection diagram of sensor interfacing and ESP32 connections

The complete circuit integrates IoT-enabled sensing and data acquisition components for wool quality monitoring. It includes:

- The ESP32 microcontroller as the central processing unit, managing sensor dataacquisition and wireless communication.
- The HX711 module and load cell for precise wool bundle weight measurement.
- The TCS34725 color sensor for detecting color and impurities in the wool.
- The SHT31 temperature and humidity sensor to monitor environmental conditions.
- The DS3231 RTC for accurate time-stamping of each data entry.
- The SD card module for local data storage and logging.
- Power regulation circuitry ensuring stable 3.3V and 5V supply from the mainbattery source.

All components are interconnected through well-defined communication protocols (I2C, SPI, UART), ensuring seamless data exchange and efficient monitoring of all parameters in real time. This modular integration provides scalability for additional sensors or communication modules in future upgrades.

V. RESULTS AND DISCUSSION



The proposed ESP32-based Wool Quality Checker was successfully designed and tested using multiple sensors with IoT communication. The system accurately measured important parameters such as weight, moisture, color, temperature, and humidity. The load cell provided stable weight readings, while the moisture sensor effectively detected moisture levels in wool samples.

The color sensor captured RGB values to identify wool shade and possible impurities, and the camera module produced clear images for basic fiber inspection. All collected data was processed correctly, stored safely, and transmitted wirelessly to the cloud platform through ESP32 connectivity. Users were able to view reports remotely without difficulty.

The system operated smoothly with low power consumption and quick response time, making it suitable for portable field use. Overall, the project achieved its goal of providing a low-cost and reliable solution for wool quality assessment. It helps reduce manual errors, improves transparency, and supports better decisions in the wool supply chain.

VI. ADVANTAGES

The proposed wool quality checker system offers several practical benefits for farmers, buyers, and manufacturers. It provides a portable and easy-to-use solution that allows on-site evaluation of wool quality without the need for specialized laboratory equipment. The system ensures more consistent and objective measurements compared to traditional manual inspection, reducing human errors and subjectivity in grading.

The integration of multiple sensors enables comprehensive analysis by measuring different parameters such as weight, moisture, color, and environmental conditions simultaneously. This multi-parameter approach improves the accuracy and reliability of quality assessment. The use of IoT technology allows real-time data transmission, making it possible to access and monitor wool quality reports remotely.

The system also supports local data storage, ensuring that information is not lost even when network connectivity is unavailable. Its low power consumption and compact design make it suitable for field applications, especially in rural areas. Overall, the system enhances transparency in the supply chain and helps in fair pricing based on actual quality.

VII. CONCLUSION

The ESP32-based wool quality checker system presented in this work provides an effective solution for real-time and on-site wool quality assessment. The system successfully integrates multiple sensors, a camera module, and IoT connectivity to measure and analyze key quality parameters. It eliminates the need for time-consuming laboratory testing and reduces dependency on manual inspection. The results demonstrate that the system is capable of delivering accurate, consistent, and reliable measurements under practical conditions. Its portable design, low power consumption, and ease of use make it highly suitable for field deployment. By enabling transparent and data-driven quality evaluation, the system benefits both farmers and buyers.

In summary, the proposed system contributes to improving efficiency, accuracy, and trust in the wool supply chain. It represents a cost effective and scalable approach that can be further enhanced with advanced technologies in the future.

VIII. REFERENCES

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