

Grain Silo Robot: An IOT-Based Automated System for Real-Time Grain Storage Monitoring Using Esp32 and Blynk

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ABSTRACT

Grain storage is a critical challenge in agricultural supply chains, with improper storage conditions leading to significant losses due to temperature rise, moisture accumulation, and pest infestation. Traditional manual monitoring methods are time-consuming, inefficient, and potentially unsafe for workers. This paper presents the design and implementation of a Grain Silo Robot — an IoT-based automated system for real-time monitoring and remote control of grain storage environments. The proposed system integrates an ESP32 microcontroller, DHT11 temperature and humidity sensor, L298N dual H-bridge motor driver, and four DC motors on a mobile robotic platform. Environmental data is transmitted wirelessly to the Blynk mobile application, enabling real-time monitoring and remote directional control of the robot via six virtual control buttons. The system was tested in a controlled enclosure simulating a grain silo, achieving temperature deviation of 0.2–0.8°C and humidity deviation of 1% RH compared to manual measurements. Battery autonomy of 3.5–4 hours and indoor Wi-Fi range of 15–20 meters were recorded. Experimental results confirm the system's reliability, low cost, and suitability for smart agricultural storage applications.

Keywords: Grain Silo Robot, IoT, ESP32, DHT11, Blynk, Grain Storage Monitoring, Smart Agriculture, Wireless Sensor Network, Real-Time Monitoring, L298N Motor Driver.

inspection — a process that is labor-intensive, inconsistent, and potentially hazardous due to confined space entry risks. Workers entering silos are exposed to grain dust, toxic gases, and oxygen-deficient environments. Furthermore, manual measurements at fixed intervals fail to capture dynamic fluctuations in storage conditions, often resulting in delayed detection of spoilage [1].

The rapid advancement of the Internet of Things (IoT) and embedded systems has created new opportunities for automating agricultural processes. IoT-based monitoring systems enable continuous, real-time collection and transmission of environmental data without human intervention. When combined with mobile robotic platforms, such systems can navigate within storage structures to collect spatially distributed data, providing comprehensive monitoring coverage [3], [4].

This paper presents the Grain Silo Robot — a low-cost, IoT-enabled mobile robotic system designed to monitor temperature and humidity conditions inside grain silos in real time. The system uses an ESP32 microcontroller with built-in Wi-Fi, a DHT11 sensor, an L298N motor driver controlling four DC motors, and the Blynk mobile application for remote monitoring and control. The robot can be directed to different silo locations using six directional commands via Blynk, enabling targeted data collection from multiple positions.

II. LITERATURE REVIEW

Patil and Kumbhar [1] proposed a smart grain storage monitoring system using Arduino and DHT11 sensors to transmit environmental data via GSM. While effective for static monitoring, the system lacked mobility and could only monitor from fixed sensor positions.

Rajput et al. [2] developed an IoT-based silo monitoring system using NodeMCU (ESP8266) and ThingSpeak cloud platform. The system demonstrated reliable wireless data

I. INTRODUCTION

Agriculture forms the backbone of the Indian economy, with grain production and storage playing a pivotal role in ensuring food security. According to the Food and Agriculture Organization (FAO), post-harvest losses in developing countries can reach up to 30% of total production, with a significant portion attributable to improper storage conditions [8]. Grain silos used for bulk storage of wheat, rice, maize, and other cereals are particularly vulnerable to spoilage caused by elevated temperature, excessive humidity, and poor ventilation.

Traditional silo management relies heavily on manual

transmission but was constrained to a single monitoring point with no remote control capability.

Kumar and Singh [3] explored ESP32 microcontrollers in IoT applications, highlighting the integrated dual-core processor, built-in Wi-Fi and Bluetooth, and low power consumption as key advantages for real-time embedded applications.

Sharma et al. [4] presented a mobile robot platform for agricultural environment monitoring, demonstrating that robotic mobility significantly improves spatial coverage of sensor data collection compared to static installations.

Verma and Gupta [5] studied the Blynk IoT platform as an effective interface for embedded system monitoring. The authors demonstrated that Blynk's virtual pin architecture enables low-latency bidirectional communication between ESP32 and mobile applications.

Desai et al. [6] reviewed wireless protocols for agricultural IoT, concluding that Wi-Fi-based systems using ESP32 provide the best balance of data rate, range, and cost for indoor monitoring scenarios such as warehouses and silos.

Based on the literature review, it is evident that while IoT monitoring systems and mobile robotic platforms have been studied independently, few works combine both into a single low-cost solution for grain silo monitoring. The proposed system addresses this gap.

III. METHODOLOGY

A. System Architecture Overview

The Grain Silo Robot is designed as a four-wheeled mobile robotic platform with environmental sensing and IoT communication. The architecture follows a three-layer model: sensing, processing/communication, and user interface.

The sensing layer uses the DHT11 sensor to measure temperature and humidity. The processing layer is the ESP32, which reads sensor data, controls motors, and transmits to the Blynk cloud. The user interface layer is the Blynk mobile application, displaying real-time readings and providing six directional control buttons.

B. Block Diagram

Fig. 1 shows the block diagram of the proposed system. The DHT11 feeds data to ESP32 via GPIO 26. The ESP32 transmits it to Blynk via Wi-Fi on Virtual Pins V6 (temperature) and V7 (humidity). The L298N receives motor signals from eight GPIO

pins and drives M1–M4. A sealed lead-acid battery (ST1025) powers the entire system.

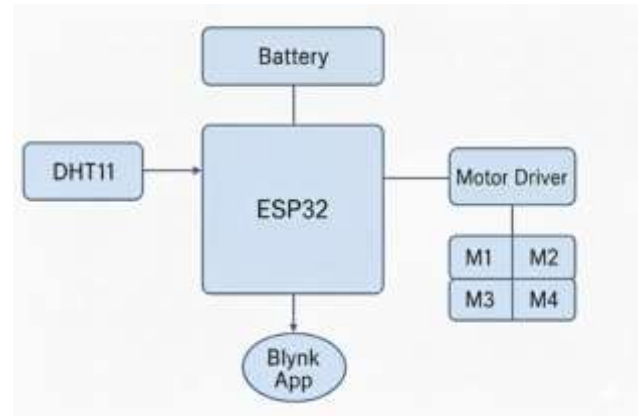


Fig. 1. Block Diagram of Grain Silo Robot System

C. Circuit Diagram

Fig. 2 shows the complete circuit diagram illustrating the interconnection of all hardware components including ESP32 GPIO pin assignments, L298N motor driver wiring, DHT11 sensor connections, battery power lines, and Wi-Fi communication path to the Blynk cloud.



Fig. 2. Circuit Diagram — ESP32, Dual L298N Motor Drivers, DHT11 Sensor and 12V Power Supply

D. System Workflow

Upon power-up, ESP32 initializes all GPIO pins, establishes Wi-Fi, and connects to Blynk cloud. The DHT11 is read every 2 seconds via BlynkTimer. Valid readings are sent to V6 and V7. The ESP32 simultaneously listens on V0–V5 for directional commands: forward, backward, left, right, rotate-left, rotate-right. Upon command receipt, the corresponding L298N

motor pattern activates. On button release, all motors stop immediately.

IV. HARDWARE AND SOFTWARE IMPLEMENTATION

A. Hardware Components

Table I lists all hardware components with specifications.

Component	Model	Function
Microcontroller	ESP32	Processing, Wi-Fi, Motor ctrl
Temp/Humidity Sensor	DHT11	Monitors silo environment
Motor Driver	L298N	Drives 4 DC motors
DC Motors	12V Gear x4	Robot locomotion
Battery	ST1025 12V SLA	Power supply
Platform	Custom Foam/Board	Robot chassis & wheels

Table I. Hardware Components and Specifications

B. GPIO Pin Mapping

GPIO Pin	Connected To	Function
GPIO 26	DHT11 Data	Sensor input
GPIO 15	L298N IN1	M1 Direction A
GPIO 2	L298N IN2	M1 Direction B
GPIO 4	L298N IN3	M2 Direction A
GPIO 16	L298N IN4	M2 Direction B
GPIO 17	L298N IN1	M3 Direction A
GPIO 5	L298N IN2	M3 Direction B
GPIO 18	L298N IN3	M4 Direction A
GPIO 19	L298N IN4	M4 Direction B

Table II. ESP32 GPIO Pin Mapping

C. Blynk Virtual Pin Mapping

V-Pin	Direction	Function
V0	App → ESP32	Forward
V1	App → ESP32	Backward
V2	App → ESP32	Left
V3	App → ESP32	Right
V4	App → ESP32	Rotate Left
V5	App → ESP32	Rotate Right

V6	ESP32 → App	Temperature (°C)
V7	ESP32 → App	Humidity (% RH)

Table III. Blynk Virtual Pin Mapping

D. Software Implementation

Firmware was developed in Arduino IDE with the ESP32 board package. Libraries used: BlynkSimpleEsp32, DHT sensor library, and WiFi.h. The DHT11 reads every 2 seconds using BlynkTimer to prevent blocking the main loop. Eight motor GPIO pins are initialized LOW at startup. The setMotorOutputs() function accepts eight boolean parameters to control all four motor directions simultaneously. Six BLYNK_WRITE handlers (V0–V5) implement forward, backward, left, right, and both rotation modes with auto-stop on button release.

V. RESULTS AND DISCUSSION

A. Experimental Setup

The robot was tested in a cardboard box enclosure simulating a grain silo. Six test runs were conducted under three conditions: normal ambient, artificially warmed, and elevated humidity. DHT11 readings from the Blynk app were compared with a calibrated reference thermometer and hygrometer simultaneously.

B. Sensor Performance

Table IV presents the sensor readings recorded during the six test runs.

Test	Condition	DHT11 Temp(°C)	Ref Temp(°C)	Dev (°C)	DHT11 Hum(%)	Ref Hum(%)	Dev (%)
1	Normal	29.4	29.0	0.4	58	57	1
2	Normal	30.1	30.5	0.4	61	60	1
3	Warm	31.6	31.0	0.6	65	64	1
4	Warm	31.0	31.8	0.8	68	67	1
5	Humid	30.8	30.5	0.3	72	71	1
6	Humid	31.2	31.0	0.2	74	73	1

Table IV. Sensor Readings — DHT11 vs. Manual Reference

C. Blynk App Interface

Fig. 3 shows the Blynk mobile application interface displaying real-time sensor data. The gauge widgets show temperature at 31°C and humidity at 29% RH. Six circular buttons (V0–V5) provide directional robot control. Data updates every 2 seconds.



Fig. 3. Blynk Mobile App Interface Showing Live Sensor Data

D. Hardware Prototype

Fig. 4 shows the internal hardware assembly. The ESP32 is mounted on a general-purpose PCB along with two L298N motor driver modules and the ST1025 12V battery. Fig. 5 shows the complete assembled robot with custom foam disc wheels providing silo-suitable mobility.

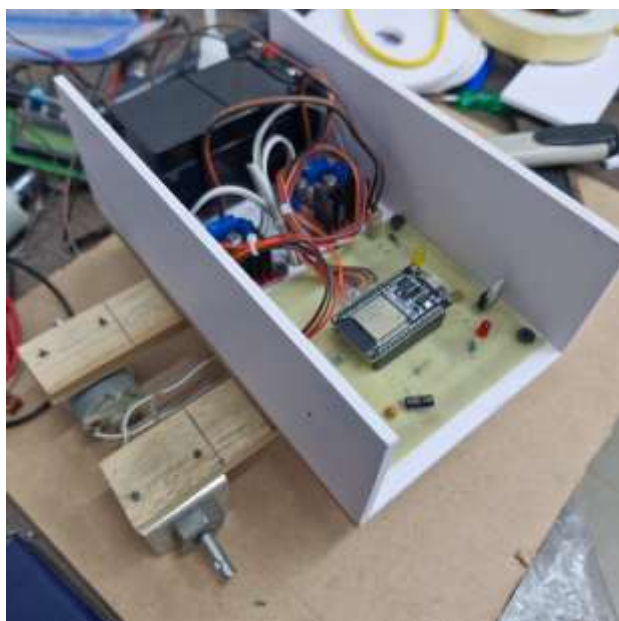


Fig. 4. Internal Hardware — ESP32, L298N Driver Modules and Battery



Fig. 5. Assembled Grain Silo Robot — External View

E. System Performance Summary

Table V summarizes overall system performance metrics.

Parameter	Observed Result
Temperature Deviation	0.2 – 0.8 °C
Humidity Deviation	1 % RH (all tests)
Blynk Update Interval	2 seconds
Wi-Fi Range (Indoor)	15 – 20 meters
Battery Life	3.5 – 4 hours (continuous)
Motor Directions	6 (Fwd/Bwd/L/R/Rot-L/Rot-R)
Total Test Runs	6

Table V. System Performance Summary

VI. ADVANTAGES AND LIMITATIONS

A. Advantages

Real-Time Monitoring: Continuous 2-second sensor updates transmitted to the Blynk app from anywhere with internet access.

Remote Robot Control: Six-direction control via smartphone eliminates manual entry into confined and potentially hazardous silo spaces.

Low Cost: Built entirely with open-source hardware at minimal component cost, making it accessible to small-scale farmers and cooperatives.

Mobility: The robot navigates to multiple silo locations for spatially distributed data collection, overcoming the limitation of fixed sensors.

Worker Safety: Eliminates risks associated with human entry into grain silos including dust inhalation and oxygen deficiency.

B. Limitations

The system is dependent on Wi-Fi connectivity, which may be unreliable in large metallic silos due to signal attenuation. The DHT11 sensor has limited accuracy compared to industrial-grade sensors and may be affected by dust accumulation. The prototype chassis is suitable for laboratory testing but requires more robust materials for real industrial deployment. The system currently monitors only temperature and humidity; CO₂ and grain level are not measured.

VII. CONCLUSION AND FUTURE WORK

This paper presented the Grain Silo Robot, an IoT-based mobile robotic system for automated real-time monitoring of grain storage conditions. The system successfully integrates ESP32, DHT11, L298N motor driver, and Blynk into a cohesive, low-cost solution. Experimental results demonstrated temperature deviations of 0.2–0.8°C and humidity deviations of 1% RH, confirming the reliability of the sensing system. The robot's mobility enables data collection from multiple silo locations, addressing the spatial limitation of static installations.

Battery autonomy of 3.5–4 hours and effective Wi-Fi range of 15–20 meters validate the system's operational feasibility. The proposed system demonstrates that affordable embedded hardware combined with IoT platforms can provide practical solutions to agricultural storage challenges.

Future Work: Replacing DHT11 with DHT22 or SHT31 for improved precision; integrating MQ-series gas sensors for CO₂ and ammonia detection; adding ultrasonic sensors for grain level measurement; upgrading the chassis for real industrial environments; implementing autonomous navigation with obstacle avoidance; and cloud-based data logging with automated threshold alerts.

VIII. REFERENCES

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