IoT-Based Motion Detection and Environmental Monitoring System for Agriculture Security Using ESP32

Hanisah Mohd Zali[1*], Nurul Husna Balqis[1], Norul Ashikin Norzain[1], Nik Nurzuliyana Mohd Rajdi[1], Hajar Jaafar[2]

[1]Faculty of Engineering, Built Environment and Information Technology, MAHSA University, Selangor, Malaysia

[2]Faculty of Electrical Engineering, UiTM Kampus Pasir Gudang, Johor, Malaysia

[*]Corresponding Author

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ABSTRACT

Manual patrolling continues to be used on many small farms to locate trespassers, any stray animals and any changes to the field conditions, leaving the site open for much of the day. The low cost Internet of Things (IoT) systems reported in literature typically concentrate on environmental sensing tasks or intrusion detection tasks, and few of them couple an on-site deterrent with off-site notification. A mini-monitoring unit with the integration of motion detection and environmental monitoring using a single ESP32 microcontroller is presented here. A passive infrared (PIR) sensor is used for detecting movement in the monitored area, a DHT11 sensor is used for measuring ambient temperature and relative humidity, and an LED and an active buzzer are used as a local visual and audible alarm. The sensor data and system status are transmitted wirelessly via Wi-Fi to the Blynk IoT platform, and a dashboard is created to display information such as the system's motion state, real-time temperature and humidity readings. The firmware was programmed using the Arduino IDE, tested on the Wokwi simulator and deployed to a breadboard prototype placed next to a scaled up planting enclosure. The two cases that were operating were assessed. In the absence of the motion, the output of the PIR remained LOW, both alarm outputs were off and the unit continued to report temperature and humidity every 2 s. Once the motion was enabled the output from the PIR was HIGH, then the LED and buzzer were turned ON in the same control cycle, the motion status report was displayed on the dashboard, and the environmental readings were not interrupted. During the tests the data of temperature and humidity were successfully displayed on the Blynk dashboard. The results confirm that the unit works as designed in both cases and that a level of farm surveillance can be realised that is practical and achieved using low cost and widely available parts at approximately RM 56 per unit. Sensing range and sensor accuracy and reliance on Wi-Fi are also addressed.

Keywords: ESP32, PIR sensor, DHT11, Blynk IoT, agriculture security

INTRODUCTION

Food supply and rural livelihoods are dependent on agriculture, but many farms are still at risk with little to do with the management of their crops. Losses are caused by trespass, theft of equipment and/or produce, and by sudden changes in temperature and humidity which stress the crop before it is noticed. Protection generally relies on the farm manager or a farm employee taking a walk on small and medium farms. This way is labor intensive, can't be continuously powered and becomes less effective as the plot expands or owner is away. New technology, the Internet of Things (IoT), has revolutionized the ways data can be gathered and analyzed in the farm. Today, remote sensing and remote action of the conditions in the field is possible, thanks to networked sensors, low-power microcontrollers, and cloud dashboards that enable swift responses (Elijah et al., 2018).

Smart sensors for temperature, moisture, nutrient, and pest monitoring have been identified as a key factor in enhancing monitoring and decision-making capabilities in precision agriculture, while some challenges such as high implementation cost, security issues, and poor rural connectivity have been reported in recent reviews (Rajak et al., 2023; Sheikh Mansoor et al., 2025). A solution must then be cheap and easy to install and must be of benefit, without any special skills, for a smallholder. Development boards like ESP32 fulfill a lot of this requirement. The board is powered by a dual core processor, has Wi-Fi connectivity, and has plenty of general-purpose input/output (GPIO) ports that allow for multiple sensors and actuators to be connected simultaneously; it is also supported by free tools including the Arduino IDE and the Blynk IoT platform.

Despite this, most published farm systems using the ESP32 only collect environmental data, with systems designed to monitor farm security more often using cloud or network level processing and rarely providing an immediate farm deterrent. If the invader or animal is not in the field, a remote alert does little to deter it at the time of need. This paper aims to fill the gap with a low-cost unit which includes physical motion detection, environmental monitoring, and a two-level alert system all in one. ESP32 reads the values from a PIR sensor and a DHT11 sensor, controls an LED and buzzer locally and pushes the motion status, temperature and humidity data to a Blynk dashboard. The components are all standard, off the shelf, and the contribution of the paper is not to be found in any individual component. It combines the two most important functions of intrusion alerting and temperature and humidity monitoring into one unit; it provides a local alarm path that remains functional in the event of the internet connection going down (which the closest ESP32 and Blynk farm protection systems don't offer (see Related Work)); and it presents the cost of the item in an itemised way so that the affordability claim can be tested. The design was tested on a prototype and in simulation. The rest of the paper summarizes the related work, outlines the system design and test procedure, reports and discusses the results, and finally concludes and outlines future development.

Related Work

Environmental monitoring is the most common application of low-cost IoT in agriculture. Putri et al. (2021) proposed an IoT framework in which temperature, humidity and soil moisture sensors were read by a microcontroller and the data forwarded to an online platform to support farming decisions. Adeagbo (2024) used an ESP32 with the Blynk application to monitor temperature and humidity remotely, highlighting the board's built-in Wi-Fi, low power use and broad sensor compatibility. Mohd Khalid et al. (2024) extended the idea to a solar-powered smart agriculture system based on the NodeMCU ESP32, showing that such units can run in the field without mains power. None of these systems, however, includes any form of intrusion detection.

Security-oriented work has taken different directions. Miao et al. (2023) designed a fog-based smart agriculture system to detect animal intrusion, moving part of the processing closer to the field to shorten the response time of alerts. Chaganti et al. (2022) proposed a blockchain-based, cloud-enabled security monitoring framework in which sensor data from ESP32 nodes are analysed in the cloud for anomalies and security events are stored on a blockchain to protect data integrity. Rahman et al. (2025) surveyed intrusion detection systems for IoT networks; this body of work is concerned with attacks on the network and devices rather than physical entry onto a farm. These approaches are capable but add infrastructure, computing cost and complexity that a smallholder may not be able to support.

Closer to the present work are low-cost prototypes that use PIR sensors for physical intrusion. Alui and Mohamed (2023) built an animal intrusion prototype with four PIR sensors, a piezo buzzer, a servo-mounted camera and Blynk notifications; the evaluation was limited to qualitative observations of detected animals, and no detection rate, false alarm rate, latency or cost was reported. Khalid and Mohammad Radzi (2024) proposed a solar-powered farm protection system using a NodeMCU ESP32, a PIR sensor, a light-dependent resistor, a buzzer, an LED and Blynk, and rated detection effectiveness qualitatively over distances up to 12 m. Neither system measures temperature or humidity, and neither reports accuracy, false alarms, response time or a cost breakdown. The present work therefore overlaps with these studies in its use of a PIR sensor, a buzzer and Blynk, and differs from them in adding temperature and humidity monitoring to the same unit and in giving an itemised cost.

Table 1 summarises these studies and Table 2 compares their features with those of the proposed unit. Taken together, they show room for a single, inexpensive unit that senses physical movement and environmental conditions at the same time and responds both locally and remotely, which is the focus of the present work.

Table 1. Summary of related work and its relation to the present study.

Study	Approach	Main focus	Gap addressed here
Putri et al. (2021)	Microcontroller with temperature, humidity and soil moisture sensors; IoT platform	Environmental monitoring	No intrusion detection or alarm
Adeagbo (2024)	ESP32 with Blynk application	Remote temperature and humidity monitoring	No motion sensing or local deterrent
Mohd Khalid et al. (2024)	Solar-powered NodeMCU ESP32	Smart agriculture monitoring	Monitoring only, no security function
Miao et al. (2023)	Fog computing architecture	Animal intrusion detection	Requires fog/edge infrastructure
Chaganti et al. (2022)	ESP32 nodes, cloud and blockchain	Security event monitoring and data integrity	Complex; not aimed at low-cost physical deterrence
Rahman et al. (2025)	Survey of IoT intrusion detection	Network-level attacks	Does not cover physical entry
Alui and Mohamed (2023)	Four PIR sensors, buzzer, servo-mounted camera; Blynk alerts	Animal intrusion detection	No environmental sensing; qualitative evaluation only
Khalid and Mohammad Radzi (2024)	NodeMCU ESP32, PIR, LDR, buzzer, LED; Blynk; solar PV	Farm protection against animals and theft	No temperature or humidity sensing; no accuracy, latency or cost data

Table 2. Feature comparison of the proposed unit with closely related low-cost systems.

Feature	Adeagbo (2024)	Mohd Khalid et al. (2024)	Alui and Mohamed (2023)	Khalid and Mohammad Radzi (2024)	This work
Motion (PIR) detection	No	No	Yes	Yes	Yes
Temperature and humidity	Yes	Yes	No	No	Yes
Local alarm (buzzer/LED)	No	No	Yes (buzzer)	Yes	Yes
Remote dashboard	Blynk	Yes	Blynk	Blynk	Blynk
Itemised cost	–	–	Not reported	Not reported	Yes (about RM 56)

– not examined in this comparison.

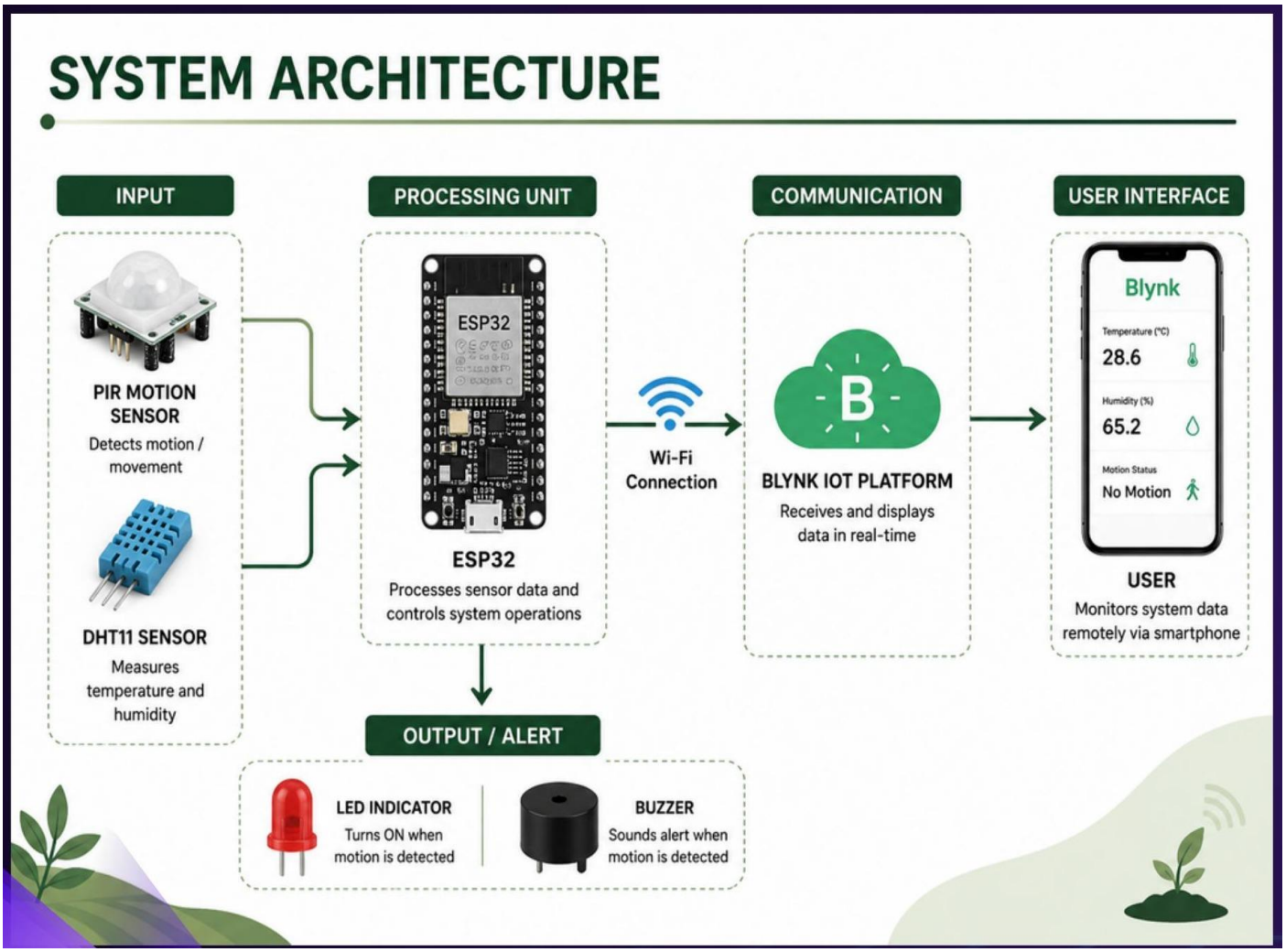
MATERIALS AND METHODS

System Architecture

The system consists of four stages (see Figure 1). The PIR sensor is monitoring for any movement in the input stage while the DHT11 sensor takes temperature and humidity readings. The ESP32 reads both sensors, implements control logic and controls the outputs. During communication: ESP32 transmits data to Blynk cloud via Wi-Fi. The user-interface phase is the Blynk Web and Mobile Dashboard, which allows the owner to

monitor the site from afar. The LED/buzzer are part of a local output path that is independent of the network, which means it will still alert the user on the premises if the internet connection drops out.

Figure 1. System architecture of the proposed monitoring unit.



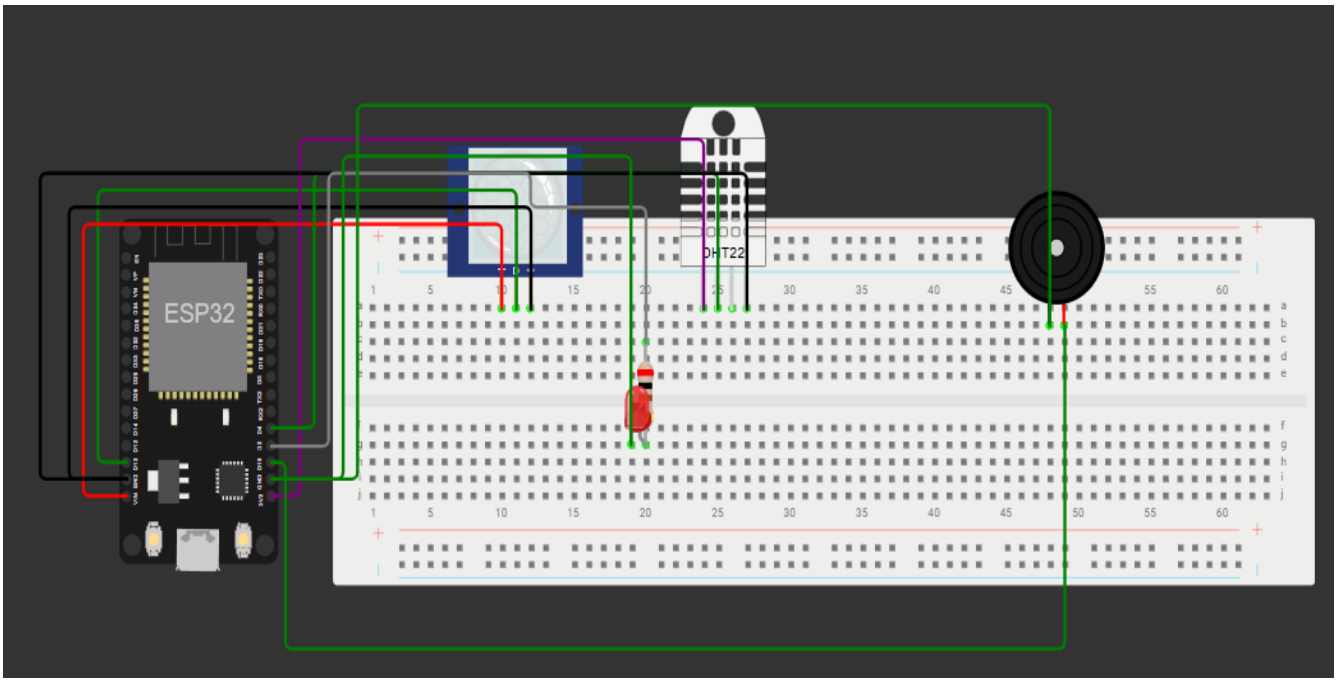
Hardware configuration

All components are listed and connected with the ESP32 in Table 3. The output of the PIR is connected to a digital input while the DHT11 communicates with the board through its data line which is single wire. The LED is controlled via a current limiting resistor, and the working buzzer is turned on from a separate digital output. All devices have a common common with ESP32 and was powered by a USB supply during the testing. The circuit was initially built in Wokwi simulator (Figure 2). Wokwi doesn't have a DHT11 model, and in simulation, it was using a DHT22 model, but both sensors use the same single-wire protocol, and the same single-wire library, except for the sensor type constant, which is different between them.

Table 3. Components and ESP32 pin assignments.

Component	Function	ESP32 connection
ESP32 development board	Main controller with built-in Wi-Fi	USB 5 V supply
PIR motion sensor	Detects movement in the monitored zone	GPIO 13 (digital input)
DHT11 sensor	Measures temperature and relative humidity	GPIO 4 (single-wire data)
Red LED with resistor	Local visual alarm	GPIO 2 (digital output)
Active buzzer	Local audible alarm	GPIO 14 (digital output)
Breadboard and jumper wires	Prototype interconnection	-

Figure 2. Hardware wiring of the system in the Wokwi simulator.



Cost analysis

The cost of the components used in the prototype is presented in Table 4, which is based on the retail price of the components obtained from Malaysian online electronics suppliers in month 2026 / purchase receipts. Use of the Blynk free plan meant no software or subscription cost, just one device and three datastreams were used. The mounting frame, planting enclosure and Wi-Fi router already installed on site is not included. The low cost claim is about RM 56 per unit; an enclosure to protect the unit from the weather and, in the case of no mains power, a solar panel and battery are not included in this.

Table 4. Cost breakdown of the prototype (indicative prices, Malaysian ringgit).

Component	Quantity	Unit price (RM)	Subtotal (RM)
ESP32 development board (DevKit V1)	1	[22.00]	[22.00]
HC-SR501 PIR motion sensor	1	[5.50]	[5.50]
DHT11 temperature and humidity module	1	[6.50]	[6.50]
5 mm red LED with 220 Ω resistor	1	[0.50]	[0.50]
5 V active buzzer	1	[1.50]	[1.50]
Breadboard (830 points)	1	[6.00]	[6.00]
Jumper wires (set of 40)	1	[4.00]	[4.00]
USB cable and 5 V adapter	1	[10.00]	[10.00]
Blynk IoT (free plan)	-	0.00	0.00
Total			**[56.00]**

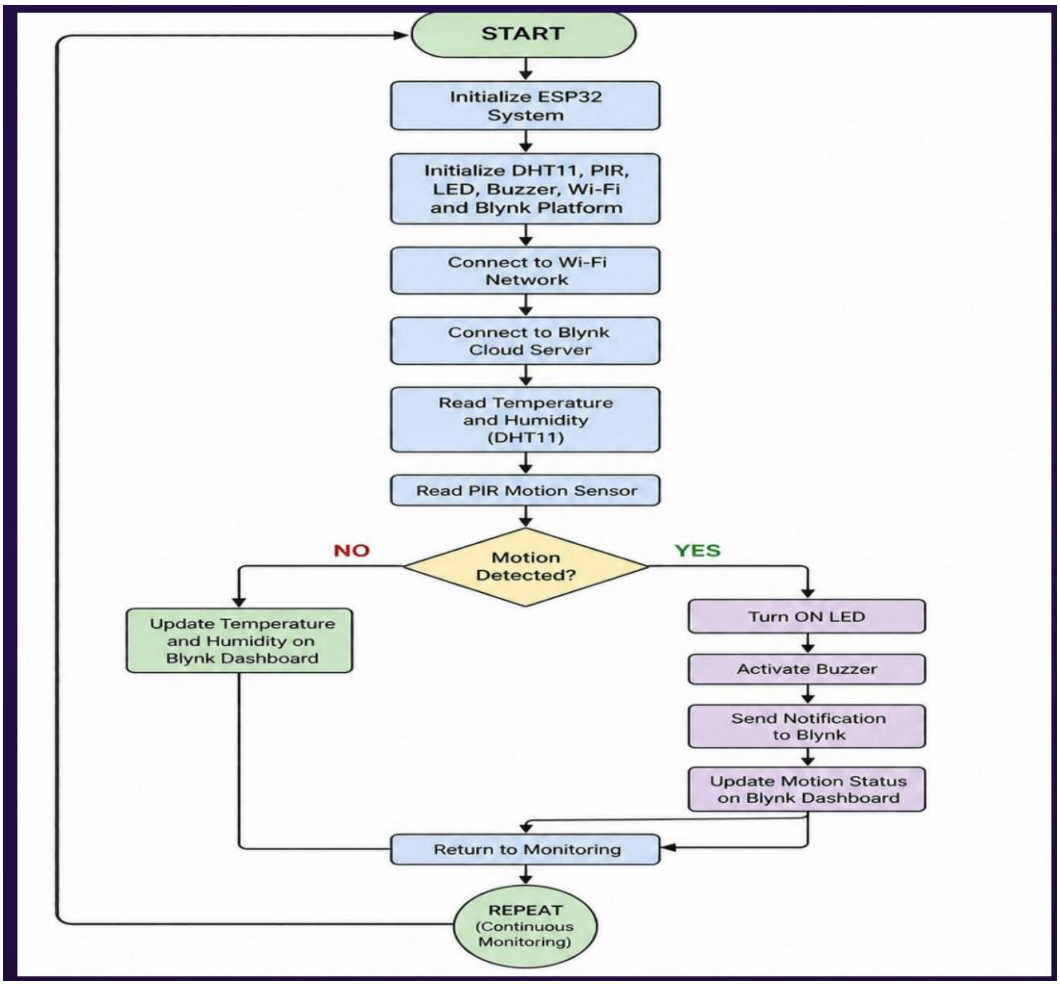
Firmware and Control Logic

The firmware was written in C++ in the Arduino IDE using the Adafruit DHT library. During start-up, the program sets the PIR pin as an input and the LED and buzzer pins as outputs, opens the serial port at 115200 baud, initialises the DHT sensor and connects to the Wi-Fi network and the Blynk server. The main loop then repeats every 2 s. In each cycle, the ESP32 reads the PIR output, temperature and humidity. If either environmental reading is invalid, an error message is reported instead of a value, which prevents corrupted data from reaching the dashboard. When the PIR output is HIGH, the LED and buzzer are switched on and a motion event is flagged; when it is LOW, both outputs are switched off. The motion state, temperature and humidity are written to Blynk virtual pins V0, V1 and V2, respectively.

Operating flow

Figure 3 shows the operating sequence. After initialisation and network connection, the unit enters a continuous monitoring loop. When no motion is present, only the environmental data are updated on the dashboard. When motion is detected, the ESP32 activates the LED and buzzer, updates the motion status on Blynk and notifies the user. The unit then returns to monitoring, so normal operation resumes without manual reset.

Figure 3. Operating flow of the monitoring system.



Test Procedure

Testing was carried out in two stages. In the first stage, the complete circuit and firmware were run in Wokwi under two cases: Case A, in which no motion is present, and Case B, in which motion is triggered from the simulator's PIR control. The serial monitor, LED state and buzzer state were recorded for each case. In the second stage, the physical prototype was installed beside a planting enclosure that represented a small farm plot. Human movement was introduced in front of the PIR sensor to check the alarm response, and the Blynk dashboard was observed to confirm that temperature, humidity and motion status were received over Wi-Fi.

RESULTS AND DISCUSSION

Prototype Implementation

The assembled prototype is shown in Figure 4. The sensors and alarm devices were mounted on a translucent panel fixed to a wooden frame, which was placed against the wall of a glass enclosure planted with vegetation to represent a crop area (Figure 4a). As seen in Figure 4b, the LED, PIR sensor and buzzer are arranged along the top of the panel facing the plot, with the DHT11 placed below the PIR sensor where it is exposed to the

surrounding air. The ESP32 is mounted at the side of the frame and connected to the sensors by jumper wires and to a USB supply (Figures 4c and 4d). This arrangement gives the PIR sensor a clear view across the planted area and keeps the wiring short. The prototype powered up, joined the Wi-Fi network and began sending data to Blynk without manual intervention.

Figure 4. Physical prototype: (a) unit installed beside the planted enclosure; (b) sensor panel with LED, PIR sensor, buzzer and DHT11; (c) top view showing the panel and ESP32 connected to a USB supply; (d) side view with the ESP32 mounted on the frame.

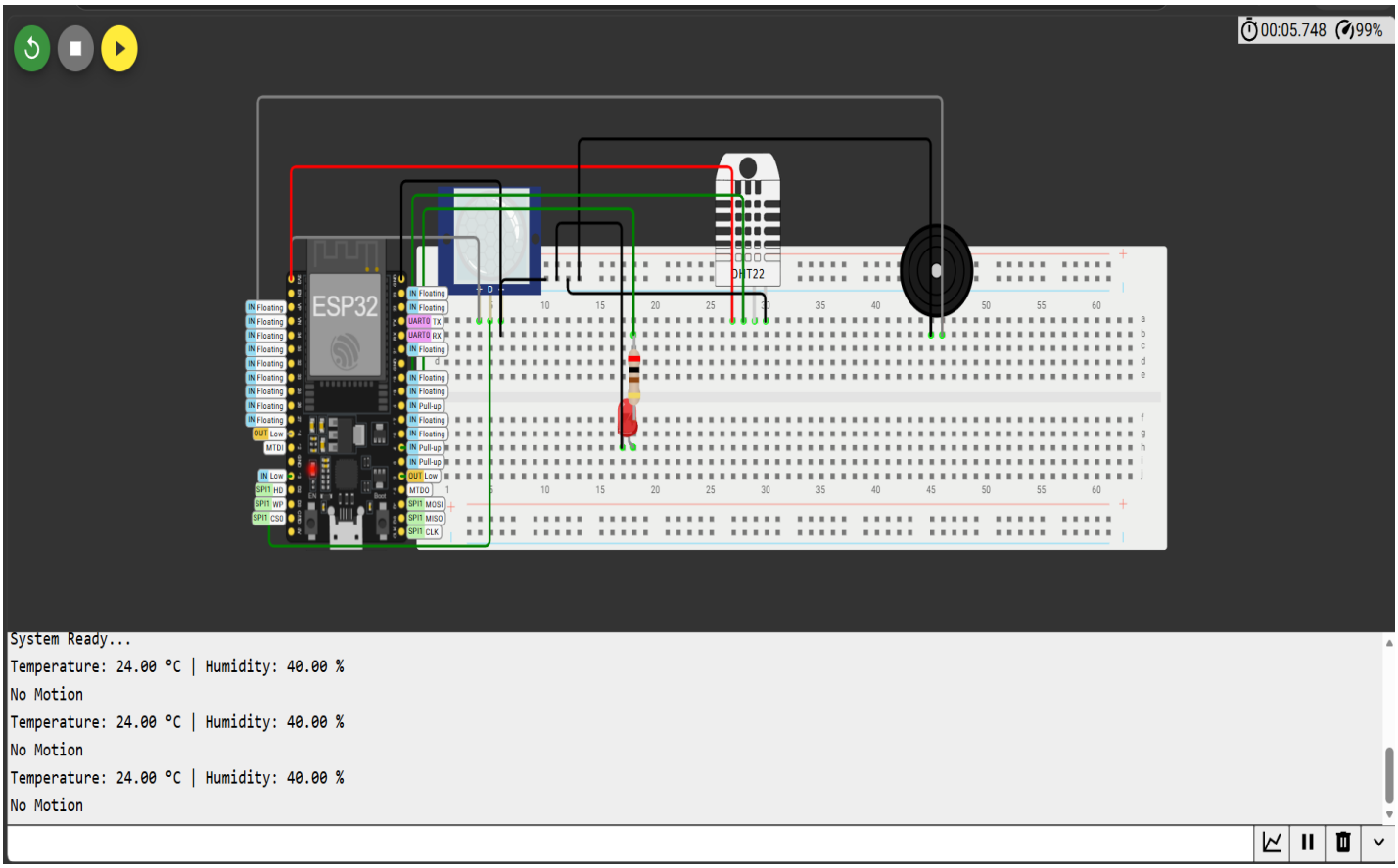


(a) (b) (c) (d)

Simulation Results

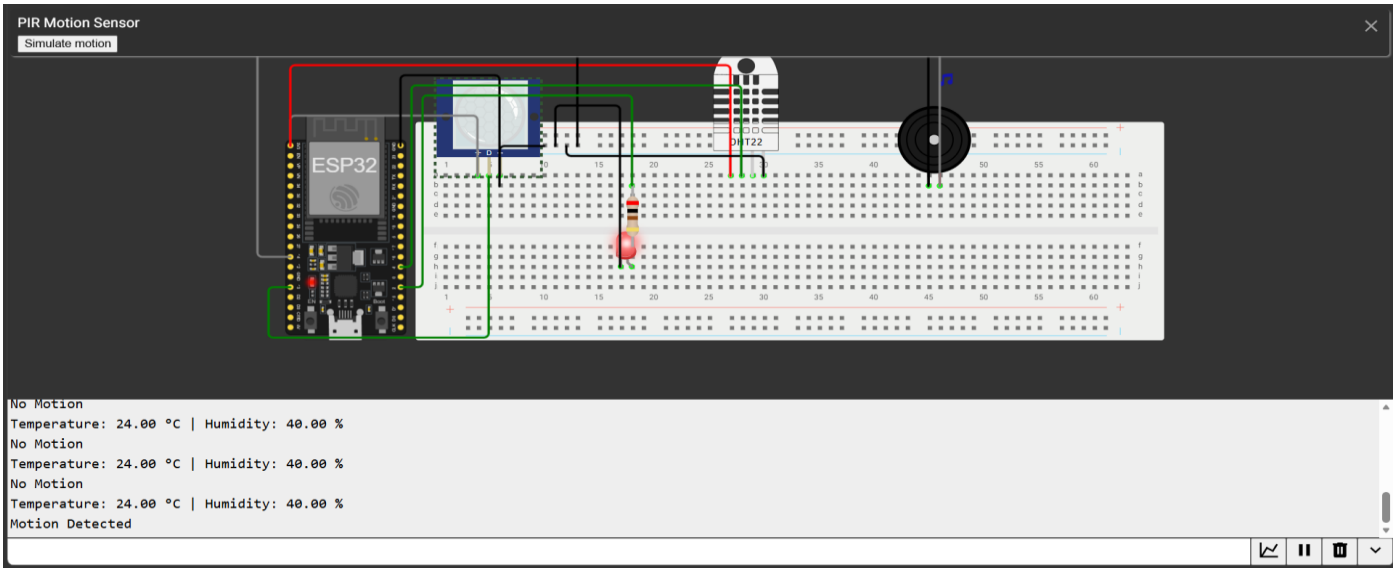
Figure 5 shows Case A. After the start-up message, the serial monitor prints a temperature and humidity reading followed by "No Motion" in every 2 s cycle. The PIR output remains LOW, and the LED and buzzer stay off, so the unit sits in a standby state in which it only monitors the environment. The constant 24.00 °C and 40.00% values are the default settings of the simulated sensor, so this test confirms the data path and loop timing rather than measurement accuracy. Importantly, no false alarm was produced while the zone was clear.

Figure 5. Simulation result for Case A (no motion detected).



Case B is shown in Figure 6. Once motion is triggered, the PIR output switches HIGH and the next cycle prints "Motion Detected". The LED lights up and the buzzer sounds, indicated by the note symbol above the buzzer. Temperature and humidity continue to be printed in the same cycle, which shows that the alarm routine does not interrupt environmental monitoring. The ESP32 therefore executes the intended control logic in real time for both conditions.

Figure 6. Simulation result for Case B (motion detected).



Hardware Functional Tests

The outcomes of the functional tests on the physical prototype are summarised in Table 5. The PIR sensor responded to human movement in front of the unit by sending a HIGH signal to the ESP32, which immediately

switched on the LED and buzzer. When the movement stopped, the output returned LOW and both alarm devices switched off. The DHT11 readings were processed by the ESP32 and displayed on the Blynk dashboard, and the values updated in real time over Wi-Fi. These results confirm that the PIR sensor is suitable for detecting a possible intrusion or animal movement in an agricultural setting and that the DHT11 provides the basic environmental information needed for routine monitoring.

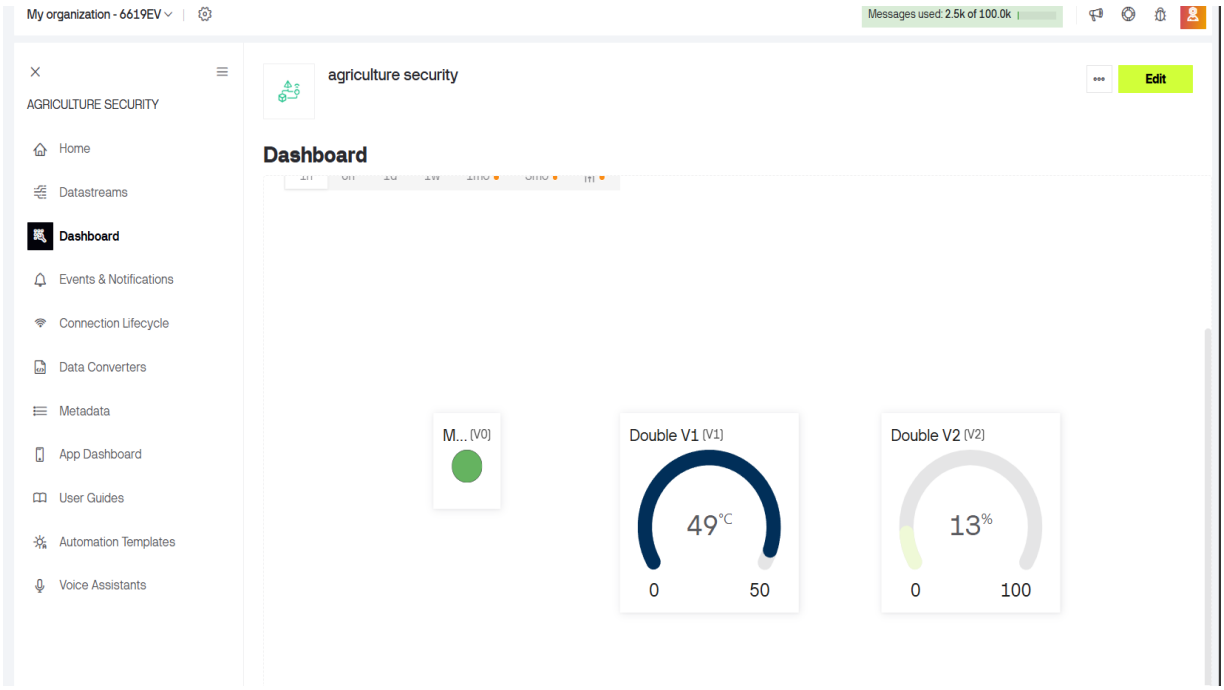
Table 5. Functional test results of the physical prototype.

Test	Condition	Observed response
PIR motion detection	No movement	PIR output LOW; LED OFF; buzzer OFF
PIR motion detection	Movement in front of sensor	PIR output HIGH; LED ON; buzzer ON
DHT11 temperature	Continuous operation	Displayed successfully on Blynk dashboard
DHT11 humidity	Continuous operation	Displayed successfully on Blynk dashboard
Data transmission	Wi-Fi connected	Real-time update to Blynk

Remote Monitoring Through Blynk

Figure 7 shows the Blynk web dashboard configured for the system. The motion indicator on V0 changes state when the PIR sensor is triggered, while two gauges on V1 and V2 display temperature on a 0–50 °C scale and relative humidity on a 0–100% scale. The same layout is available in the Blynk mobile application, so the owner can check the site from any location with internet access instead of travelling to it. This remote view complements the local alarm: the buzzer and LED act as an immediate deterrent at the field, while the dashboard keeps the owner informed.

Figure 7. Blynk IoT dashboard showing the motion indicator (V0), temperature gauge (V1) and humidity gauge (V2).



Comparison of Operating Cases

Table 6 compares the system behaviour in the two cases. In Case A, only environmental monitoring is active and the alarm outputs are off. In Case B, environmental monitoring continues normally while the LED and buzzer are switched on together. The alarm is therefore raised only when motion is present, which avoids unnecessary alerts and confirms that the system functions as intended.

Table 6. Comparison of system behaviour under the two operating cases.

Condition	PIR sensor	DHT11 sensor	LED	Buzzer	System behaviour
Case A: no motion	LOW (inactive)	Reading normally	OFF	OFF	Standby; environmental monitoring only
Case B: motion detected	HIGH (active)	Reading normally	ON	ON	Alert raised; monitoring continues

DISCUSSION

The proposed unit has a physical intrusion detection and local alarm unlike the environmental monitoring systems of Putri et al. (2021) and Adeagbo (2024), but does not add any hardware cost other than a PIR sensor, an LED and a buzzer. It has been designed with compromises to the security of the frameworks of Chaganti et al. (2022) or Miao et al. (2023) in exchange for being built with common components and free software, and maintained by a small farm. The primary benefit is that it has two notification options: the local alarm will activate even when there is no internet connection and the remote dashboard will activate when the site owner is not present.

There were a number of limitations. First, it has a bounded response time, with the 2 s loop delay allowing for a motion event to wait up to one cycle before the alarm is raised. If the PIR sensor could be read in hardware interrupt, this delay would be eliminated. Secondly, a single PIR sensor has a limited range of use, and limited field of view, and can be affected by temperature changes, direct sunlight or physical obstructions, larger plots would require multiple units or more sensors with the wider coverage. Thirdly, the DHT11 is expected to be accurate to roughly ±2 °C and ±5% relative humidity, which is suitable for general purposes such as awareness but not for more specific needs like greenhouse control. Lastly, remote alerts require a stable Wi-Fi connection, which may not be possible in rural locations but would require a long-range link like LoRa or a GSM module. The PIR sensor is also unable to differentiate between movement of a human being, a farm animal or a pest, thus any movement detected is viewed as an intrusion.

CONCLUSION

Agriculture security motion detection and environmental monitoring unit based on IoT was designed, simulated and fabricated with the help of ESP32, PIR sensor, DHT11 sensor, LED, active buzzer and Blynk IoT platform. The tests using simulation and hardware demonstrated that the unit remains in standby without any false alarms when the zone is clear, activates the local alarm and updates the dashboard when motion is sensed and reports temperature and humidity continuously in both cases. The results indicate that the design is practical and can be implemented with low cost, widely available parts, making it suitable for small and medium farms that currently don't have any monitoring. For further work, an ESP32-CAM module will be added with a model for image classification to distinguish individuals, animals and pests, soil moisture sensors, rain and light sensors will be installed, DHT11 will be replaced by a more precise sensor, interrupt-driven motion detection will be added and LoRa communication will be evaluated and will be used, together with solar power, in remote locations.

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