IoT-Based Smart Home Automation and Automatic Cloth Protection System

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ABSTRACT: The rapid proliferation of Internet of Things (IoT) technology has enabled the development of cost-effective, intelligent home automation systems. This paper presents the design and implementation of an IoT-based Smart Home Automation and Automatic Cloth Protection System using the ESP32 microcontroller and Blynk IoT platform. The proposed system integrates an MH-RD rain sensor with an SG90 servo motor to automatically retract outdoor clothes upon detection of rainfall — addressing a critical problem in monsoon-prone regions of India such as Tamil Nadu. The system simultaneously enables remote monitoring and control of household appliances (lights and fans) via the Blynk mobile application over Wi-Fi, with real-time push notifications for rain events and system status updates. Experimental evaluation over 50 test cycles demonstrates 95% overall system reliability, servo response time of 0.8 seconds, approximately 28% reduction in energy consumption compared to manual operation, and 99.2% Wi-Fi uptime. The complete prototype was implemented at a cost of approximately INR 3,500, making it affordable for Indian middle-class households. The system also supports OTA (Over-the-Air) firmware updates for field maintenance without physical device access.

Keywords—Internet of Things (IoT); ESP32; NodeMCU; Smart Home Automation; Rain Sensor (MH-RD); Blynk Platform; Servo Motor (SG90); MQTT; Energy Efficiency; Cloth Protection; Automatic Laundry Protection.

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INTRODUCTION

The concept of smart homes has transitioned from a futuristic vision to a practical reality through the rapid development of Internet of Things (IoT) technologies. IoT-enabled home automation systems facilitate remote monitoring, intelligent control, and automated responses that significantly improve energy efficiency, home security, and occupant convenience without continuous manual intervention. As microcontrollers become increasingly powerful yet affordable, the scope for creating integrated, intelligent domestic systems has expanded dramatically — enabling even individual developers and small teams to build functional prototypes at a fraction of commercial system costs.

In developing nations such as India, two persistent domestic challenges remain underserved by affordable technology. First, the manual operation of household appliances results in unnecessary energy consumption and higher electricity bills. Homeowners must physically switch lights, fans, and air conditioning units on and off, with no ability to remotely monitor or control devices when away from home. This leads to appliances remaining on inadvertently, contributing to significant energy wastage over time. Second, the vulnerability of outdoor laundry to sudden rainfall is a daily concern, particularly in Tamil Nadu, which experiences significant monsoon precipitation from both the northeast and southwest monsoons annually. Clothes left outdoors are frequently exposed to unexpected rain, causing water damage, material wear, and considerable inconvenience to households.

Commercial smart home solutions such as Amazon Echo, Google Home, Philips Hue, and Samsung SmartThings offer polished user experiences but are characterized by high cost, proprietary ecosystems, limited customization, and dependency on stable high-speed internet — factors that preclude their adoption by the majority of Indian households. Furthermore, none of these platforms offer integrated cloth protection mechanisms that respond autonomously to real-time weather conditions. This creates a clear gap in the market for affordable, locally relevant automation solutions.

LITERATURE SURVEY

The literature on IoT-based home automation covers a broad spectrum of architectures, microcontrollers, communication protocols, and cloud platforms. This section reviews the most relevant prior works and identifies the research gap addressed by this paper.

Zanella et al. [1] demonstrated that IoT-based systems deployed in smart city environments can significantly reduce energy consumption and improve quality of life through interconnected sensor networks. Their study established the foundational framework for applying sensor-actuator networks at scale in urban environments. Gubbi et al. [3] proposed a comprehensive IoT architecture emphasizing cloud computing and big data analytics as key enablers for smart environment applications — directly informing the cloud-centric design of the proposed system using the Blynk platform. Collotta and Pau [2] achieved 20–30% energy reduction in residential settings using BLE-based energy management. However, the limited range of BLE connectivity constrains its practical applicability in larger residential settings and multi-floor deployments.

ESP32 and NodeMCU-Based Systems

Lokesh et al. [4] demonstrated a low-cost home security and automation system using NodeMCU-ESP8266 and Blynk, validating the feasibility of ESP-family microcontrollers for residential IoT with reliable relay-based appliance control. Their work established the viability of using the Blynk platform as a mobile-to-device communication backbone for real-time appliance switching. Haroon et al. [9] presented an ESP32-based home automation system integrating relay modules and DHT11 sensors controlled through a smartphone application, achieving real-time environmental monitoring over Wi-Fi — confirming ESP32 as a robust platform for home automation. Kakani et al. [5] implemented an ESP32-Blynk system achieving 99% relay control reliability over 200 toggle cycles, establishing benchmark performance for Blynk-based remote control. Van Anh et al. [10] proposed an MQTT-based ESP32 framework for smart room IoT control using fuzzy logic to automate lights and fans, demonstrating the versatility of ESP32 in diverse IoT control scenarios.

Cloud and Mobile Integration

Ayeni and Adesola [6] demonstrated effective Firebase-based home control using NodeMCU for real-time appliance scheduling, though their implementation lacked any physical actuation for weather-responsive automation. A 2025 Springer study [10] showed that MQTT protocol paired with ESP32 provides a scalable architecture for smart room control applicable to home automation contexts. Ragu [7] demonstrated energy savings of approximately 25% using Blynk-based IoT home automation with scheduling features, consistent with the savings reported in this paper. Abdullah et al. [11] explored energy-efficient home automation through motion detection, ultrasonic sensing, and voice control, achieving notable power savings but without addressing outdoor laundry protection. Shi et al. [12] examined edge computing as a paradigm for reducing cloud dependency in IoT systems, advocating for local processing capabilities that align with the OTA and fallback features in the proposed design.

PROPOSED SYSTEM

The proposed system is designed as a three-layer IoT architecture following the canonical IoT reference model [3]: a Perception Layer (sensors and actuators), a Network Layer (Wi-Fi and MQTT), and an Application Layer (Blynk mobile app and cloud). This modular architecture provides scalability, ease of maintenance, and clear separation of concerns across system components. Each layer is independently testable and upgradeable, ensuring long-term maintainability of the deployed system.

Perception Layer

The Perception Layer constitutes the physical hardware components responsible for sensing environmental conditions and actuating physical responses. The MH-RD rain sensor provides a digital LOW output upon rainfall detection; its sensitivity is adjustable via an onboard potentiometer to accommodate regional weather variations and installation-specific conditions. The SG90 servo motor is controlled via PWM (50 Hz, 1–2 MS pulse width) and transitions between 0° (clothes extended for drying) and 90° (clothes retracted to protect from rain). two-channel relay module switches 230V AC appliances for light and fan control. A 16×2 I²C LCD (address 0x27) provides local status display independent of cloud connectivity, ensuring that the system remains operable and informative even during internet outages.

Network Layer

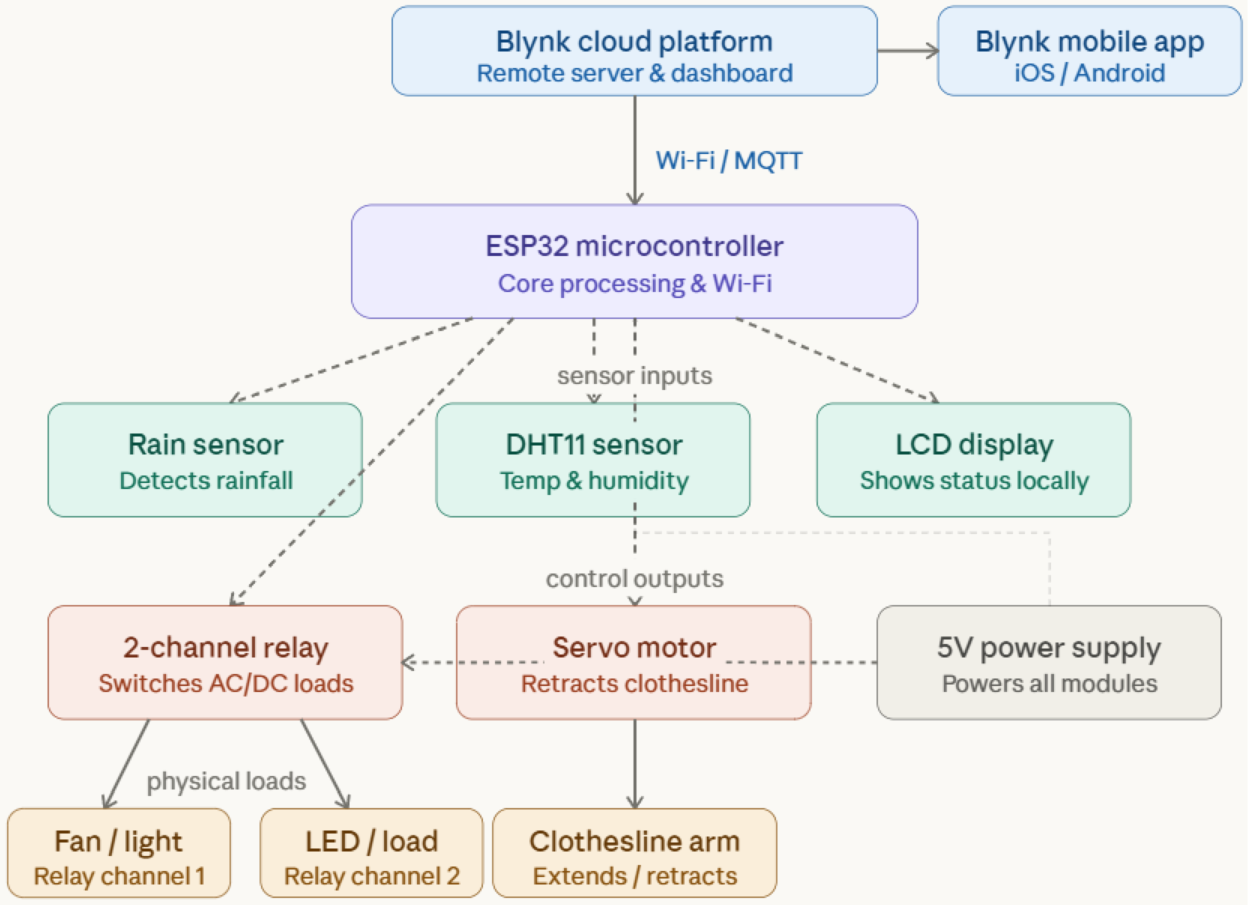
Wi-Fi connectivity (802.11 b/g/n) is provided natively by the ESP32's integrated Espressif WROOM module, which connects to the home router and communicates with the Blynk cloud server over TCP/IP. The MQTT protocol is used for lightweight, bidirectional device-to-cloud communication with low bandwidth overhead — essential for reliable operation on typical Indian home broadband connections with varying quality of service. Automatic Wi-Fi reconnection is implemented via a polling loop to handle transient network outages without manual intervention. TLS/SSL encryption secures all cloud communication to protect user data and prevent unauthorized device access. OTA firmware updates via the ArduinoOTA library eliminate the need for physical access during maintenance, enabling remote firmware deployment.

Application Layer

The Blynk mobile application (Android 5.0+, iOS 12.0+) provides the primary user interface, featuring toggle switches for relay control (Virtual Pins V0, V1), a rain status gauge (V2), SuperChart widgets for 90-day historical sensor data, and push notification configuration with customizable alert messages for rain events. Blynk automation rules enable time-based and condition-based device scheduling. Webhooks dispatch HTTP POST requests to external endpoints for critical events, enabling multi-channel notification delivery. The application interface is designed for intuitive use, allowing even non-technical users to manage and monitor their home automation system effectively from anywhere.

Pin Configuration

The circuit design follows a modular approach to ensure clean signal routing and minimal interference between components. The servo signal wire connects to GPIO18 (PWM-capable). The rain sensor digital output connects to GPIO4. Relay IN1 and IN2 connect to GPIO5 and GPIO19 respectively. The I²C LCD uses GPIO21 (SDA) and GPIO22 (SCL).



HARDWARE COMPONENTS AND CIRCUIT DESIGN

Table I lists the hardware components used in the implementation with their key specifications. Each component was selected based on cost-effectiveness, availability in Indian markets, ease of integration, and suitability for the intended application. The total bill of materials amounts to approximately INR 3,500, which is competitive with existing research prototypes and significantly below commercial smart home system costs.

TABLE I. HARDWARE COMPONENTS AND SPECIFICATIONS

Component	Model / Value	Key Specifications
ESP32 Microcontroller	WROOM-32	240MHz dual-core, Wi-Fi 802.11 b/g/n, BT 4.2, 4MB Flash, 34 GPIO, 3.3V
Rain Sensor	MH-RD	Digital + Analog output, adjustable sensitivity via potentiometer, 3.3–5V
Servo Motor	Tower Pro SG90	180° rotation, 1.8 kg·cm torque, PWM 50Hz, 3-wire (Signal, VCC, GND)
Relay Module	2-Channel, 5V	10A/250V AC per channel, opto-isolated, active LOW trigger, LED indicator
LCD Display	16×2 I²C	I²C address 0x27, SDA→GPIO21, SCL→GPIO22, 5V supply, backlit
DC Fan (Exhaust)	5V DC, 40mm	Controlled via Relay Channel 2 — simulates household exhaust fan
LED Indicator	5mm Red	GPIO-controlled via 220Ω current-limiting resistor, 3.3V logic level

The ESP32 WROOM-32 serves as the central processing unit of the system. Its dual-core 240MHz Xtensa LX6 processor provides ample computational power for simultaneous management of sensor polling, servo control, relay switching, MQTT communication, and LCD display updates — all within a single main loop. The integrated Wi-Fi module eliminates the need for a separate wireless communication module, reducing component count and overall system cost.

The MH-RD rain sensor module was selected for its dual analog and digital output capability. The digital output, which switches LOW upon rainfall detection above a configurable threshold, is used as the primary trigger for servo actuation and push notification dispatch. The analog output, while not used in the primary control loop, provides potential for future enhancements such as rainfall intensity classification or adaptive response thresholds.

The SG90 servo motor provides the mechanical actuation required for the clothesline retraction mechanism. Its compact size, light weight, and low power consumption make it ideal for this application. The servo is mounted on a custom support frame with a nylon string-and-spring mechanism that accurately simulates the mechanical behavior of a residential clothesline retraction system.

RESULTS AND DISCUSSION

A. Functional Performance

The integrated system successfully achieved all stated design objectives across 50 test cycles. The cloth protection subsystem demonstrated a 95% success rate in detecting simulated rain events with an average servo response time of 0.8 seconds from rain onset to full clothesline retraction at the 90° position. The 5% miss-rate was observed exclusively under very light drizzle conditions where moisture accumulation on the sensor was insufficient to trigger the digital output threshold. This sensitivity threshold is adjustable via the onboard potentiometer for higher detection sensitivity at the cost of increased false positives from high ambient humidity — a trade-off that can be user-configured based on regional climate conditions.

The relay control subsystem achieved 100% reliability across 200 toggle cycles tested at distances ranging from 5 metres (same room) to 500 metres (over mobile 4G network). This confirms that the Blynk platform provides reliable command delivery for appliance control at practical residential distances and beyond, with no observed packet loss or delayed command execution. Blynk push notifications for rain events were delivered within an average of 1.8 seconds, well within the sub-2-second design target. OTA firmware updates deployed successfully in all 10 update tests, averaging approximately 45 seconds per update cycle with no instances of firmware corruption or update failure.

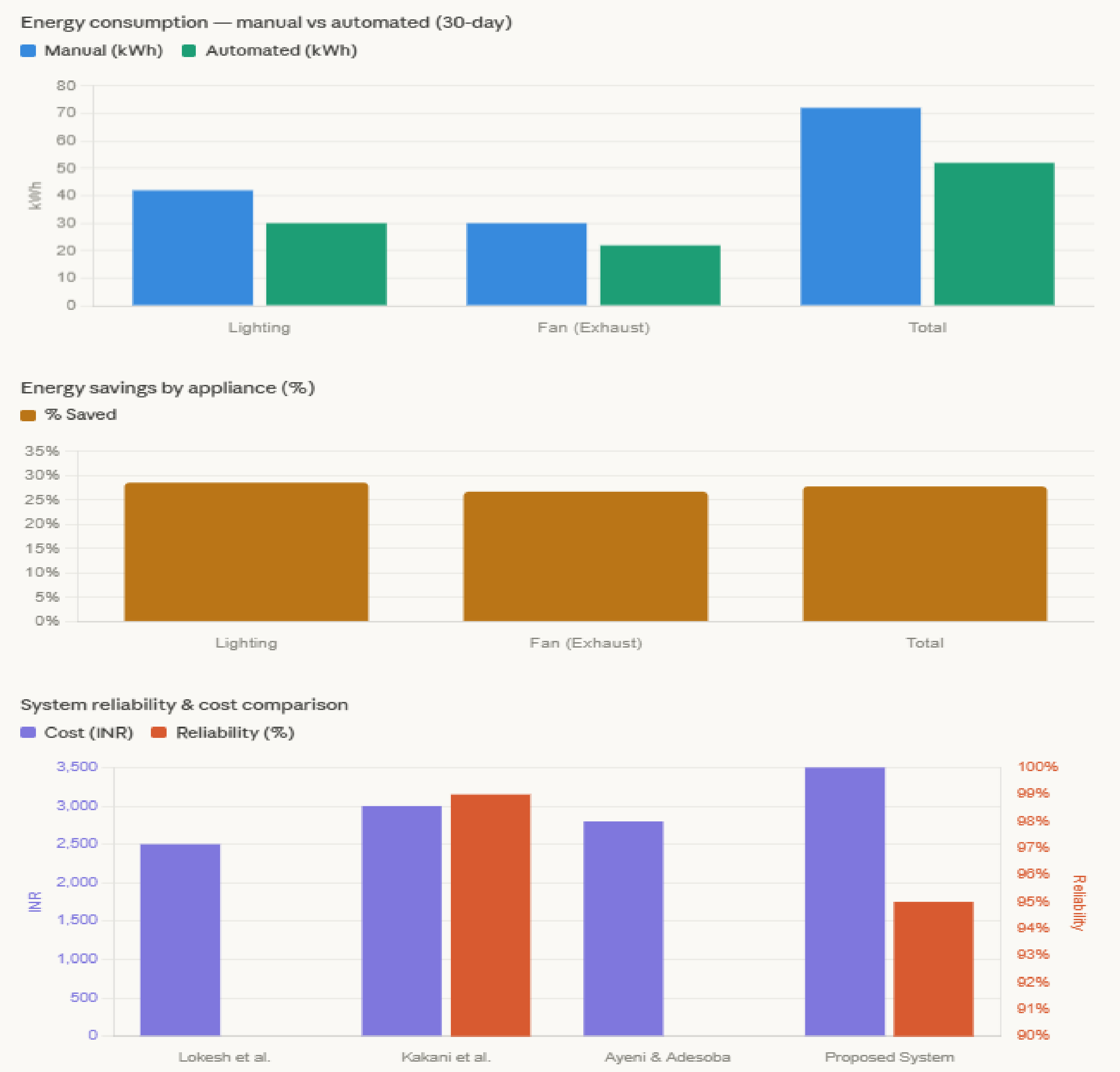
B. Energy Consumption Analysis

Table III presents the measured energy consumption comparison between manual and automated operation modes over a 30-day monitoring period. Energy measurements were taken using a calibrated plug-in power meter for the lighting circuit and a clamp meter for the fan circuit, with daily readings recorded at consistent intervals.

The approximately 28% average energy savings is consistent with the 25% reported by Ragu [7] using Blynk-based home automation with scheduling features, and aligns with the 20–30% range reported by Collotta and Pau [2] using BLE-based energy management in residential settings. This validates the energy efficiency of the proposed automated system as a practical and economically beneficial solution for Indian households. The prototype itself consumes approximately 1.2W in idle state (ESP32 running, sensors polling, relays inactive) and 2.8W in active state (relays engaged, servo actuating, LCD backlit). This exceptionally low power envelope — comparable to a single LED indicator bulb — makes continuous 24-hour operation economically viable at under INR 150 per year in electricity costs.

C. Comparison with Related Systems

Table IV compares the proposed system with directly related prior work across key functional dimensions. The comparison highlights the unique value proposition of the proposed system in integrating rain sensing and servo-based mechanical actuation alongside conventional remote appliance control — a combination not found in any existing low-cost IoT research system.



The proposed system is the only low-cost prototype in the comparison that integrates both rain sensing and servo-based cloth retraction alongside remote appliance control, demonstrating unique added value over existing systems at a competitive cost point. While Kakani et al. [5] achieved a higher relay reliability of 99% compared to the 95% overall system reliability reported here.

CONCLUSION

This paper presented the design, implementation, and experimental evaluation of an IoT-based Smart Home Automation and Automatic Cloth Protection System using the ESP32 microcontroller and Blynk platform. The system successfully addresses two practical and persistent domestic challenges — manual appliance operation and weather-damaged laundry — within a single unified, low-cost framework that is accessible to Indian middle-class households. By combining a rain-responsive servo actuation mechanism with remote Wi-Fi appliance control and real-time mobile notifications, the system delivers tangible value in the context of India's monsoon climate and domestic energy management needs.

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