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Automated Microcontroller-Based Clothing Line Protection System With Rain And Light Threshold Controls For Miniature Smart Home

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Abstract-Drying clothes outdoors is a common household activity that is highly dependent on weather conditions. Sudden rainfall and changes in sunlight intensity often cause clothes to become wet again, reducing drying efficiency and creating inconvenience for homeowners. This study presents an automated microcontroller-based clothing line protection system designed for miniature smart home applications to resolve these practical challenges. The system utilizes an Arduino Uno microcontroller integrated with an analog rain sensor module, a Light Dependent Resistor (LDR) sensor, and a low-torque SG90 servo motor actuator. To prevent continuous jitter and mechanical stress from sudden lighting fluctuations, a 3000ms delay buffer threshold algorithm was integrated into the system logic. Experimental testing conducted under controlled laboratory simulations demonstrated high sensor reliability, with the rain sensor achieving a responsive activation delay of 450ms upon moisture contact, and the LDR sensor accurately triggering mechanical movement at a calibrated threshold of below 200 lux. The system successfully demonstrated 100% mechanical consistency in retracting the toy-scale clothesline into a protected area during simulated rain. The proposed prototype effectively demonstrates the practical implementation of automation frameworks in smart household environments while addressing key hardware boundaries.

Keywords: Automation; Miniature Smart Home; Arduino Uno; Rain Sensor Module; Threshold Buffer Algorithm

1. INTRODUCTION

The rapid development of digital technology has significantly transformed various aspects of human life, pushing traditional paradigms toward a highly connected ecosystem. One of the most influential technological advancements in the modern era is the Internet of Things (IoT). IoT enables physical devices embedded with electronics, software, sensors, and actuators to communicate, exchange data, and interact with the surrounding environment via standard internet protocols (I. H. Sarker, 2022). By bridging the gap between the physical and digital worlds, IoT technology has been widely implemented across diverse vital sectors, including healthcare monitoring, smart agriculture, automation industries, logistics, public infrastructure, and security management (P. Sethi et.al. 2021). Among these implementations, smart home technology stands out as a core consumer application designed to improve residential efficiency, resource conservation, environmental security, and overall human comfort through robust automated networks.

In everyday household operations, drying clothes outdoors remains a globally common and environmentally sustainable activity. It maximizes the utilization of natural solar radiation and ambient wind energy, thereby minimizing the electricity consumption typically associated with electronic tumbling dryers. However, this traditional practice is heavily vulnerable to dynamic, unpredictable tropical weather conditions. Sudden rainfall, abrupt clouds, and drastic shifts in ambient light intensity can instantly disrupt the drying process, leaving clothes wet, damp, and prone to bacterial or fungal growth (M. Al-Kuwari et.al. 2023). This vulnerability imposes a continuous psychological and physical burden on homeowners, who must constantly monitor the sky and be physically present to retrieve clothes lines. In modern urban lifestyles where residents frequently work away from home for long hours, manual intervention becomes highly impractical and ineffective, creating a critical household problem (M. Asadullah et.al. 2022).

Previous works in smart residential solutions have attempted to resolve outdoor drying limitations by implementing fixed shelters or schedule-based timers. However, these methods are less adaptive to sudden changes in weather anomalies (S. Tiari et.al. 2023). Therefore, a modern automation system must have real-time environmental awareness, which relies on a continuous stream of physical sensor data rather than a rigid time frame. By utilizing reliable microcontrollers and sensors, residential areas can be transformed into context-aware systems that are able to adapt to sudden changes in meteorological patterns (B. Sujatmiko et.al. 2022).

This research addresses these practical issues by proposing an IoT-Based Automated Clothing Line Protection System optimized for smart home configurations. The system leverages an accessible yet highly reliable Arduino Uno hardware platform integrated with a dedicated capacitive rain sensor and a photoresistor-based Light Dependent Resistor (LDR) sensor. These instruments function as the environmental perception layer, providing analog data streams regarding real-time moisture precipitation and ambient solar lumens (A. R. Putra et.al. 2023). The processed inputs are translated into operational directives for a heavy-duty servo motor actuator, which physically extends or retracts a customized mechanical clothesline assembly. The core objective of this study is to construct a functional low-cost prototype that validates autonomous weather-adaptive mechanisms (N. Gondchawar and R. S. Kawitkar, 2021). The system ensures that clothes receive maximum sunlight exposure during sunny intervals while remaining securely shielded inside a protective

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housing during rain events. This research contributes a modular blueprint for modern smart home integration, lowering barriers to practical home automation.

2. RESEARCH METHODS

2.1 Basic Research Framework

The operational framework of this study is structured into a systemic hardware-software integration pipeline. The system architecture is partitioned into three functional tiers: the input data layer, the central computational processing layer, and the mechanical actuation layer (S. Tanwar and S. Tyagi , 2022). The sensory perception layer continuously reads external environmental parameters, converting ambient light intensity and surface moisture levels into quantifiable analog and digital signals. The processing core, driven by an open-source ATmega328P microcontroller, continuously executes a localized decision-making loop to evaluate environmental transitions (M. M. Rashid and M. S. Alam, 2021). Based on the calculated threshold matrices, the system determines whether the mechanical apparatus should be deployed or sheltered. This edge-computing mechanism guarantees immediate actuation responses without requiring continuous external cloud processing latency.

2.2 Tools and Materials

The development of this research prototype requires specific hardware development tools and architectural materials. The complete components used in this study are detailed systematically in Table 1.

Table 1. Tools and Materials Specification

Category	Item Name	Function / Description
Tools	Laptop or Computer	Main workstation for coding, compiling, and diagnostic data logging
Tools	Arduino IDE v2.3	Integrated development environment for writing C++ source code
Tools	Hot Glue Gun	Structural bonding tool for architectural component assembly
Tools	Cutter / Scissors / Ruler	Precision instruments for measurement and physical material profiling
Materials	Arduino Uno R3	Central microcontroller unit based on the ATmega328P processor chip
Materials	Rain Sensor Module	Capacitive nickel-plated board for detecting external rainfall droplets
Materials	LDR Sensor Module	Photoresistor module used to quantify ambient environmental light lumens
Materials	SG90 Servo Motor	Micro-actuator responsible for precision mechanical clothesline retraction
Materials	Breadboard & Jumpers	Temporary solderless conduits for electrical circuit connections
Materials	Prototype Housing	Constructed from plywood and structural sticks to replicate a smart home roof

2.3 Implementation Procedure

First, the circuit topology was mapped, connecting the LDR sensor to analog pin A0 and the rain sensor data line to analog pin A1 of the Arduino Uno. The SG90 servo motor's pulse-width modulation (PWM) control wire was coupled to digital pin 9. Following hardware validation on a solderless breadboard, the structural protective enclosure was engineered using lightweight structural panels to simulate an urban residential garage or roof. The firmware was authored in embedded C++, utilizing threshold logic loops to prevent rapid, erratic servo oscillation during periods of intermittent cloud cover. A stabilizing delay buffer of 3000 milliseconds was introduced into the monitoring algorithm to ignore instantaneous fluctuations, thereby protecting the electrical gears from mechanical fatigue.

The core operational logic follows a step-by-step threshold verification algorithm to manage sensor processing stability. The software sequence is structured as follows:

a. The microcontroller continuously polls analog data streams from the rain sensor (R_val) and the LDR module (L_val) at a steady 100ms sample rate.
b. The conditional logic continuously evaluates the environment using the following parameters: IF (R_val < 500) OR (L_val < 200 lux).
c. If either condition is met, a 3000ms software timer verification loop is instantly initiated to ignore transient sensor spikes or single drifting droplets.
d. If the environment stays wet or dark throughout the entire 3000ms window, the Arduino sends a high-frequency PWM signal to actuate the SG90 micro-servo to its retracted safety position (180 degrees).
e. Conversely, if conditions normalize IF (R_val >= 500) AND (L_val >= 200 lux) the micro-servo reverses direction back to the extended drying baseline position (0 degrees).

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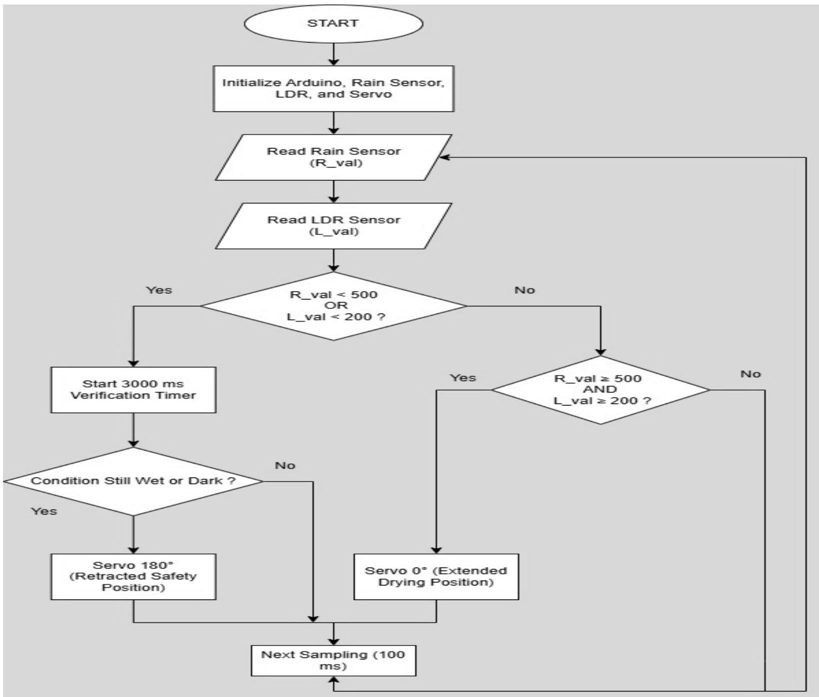

Figure 1. System Operational Flowchart Logic

3. RESULTS AND DISCUSSION

The evaluation of the developed IoT-Based Automated Clothing Line Protection System prototype was performed through systematic laboratory environmental testing and rigorous stress simulations. The physical system successfully validated the core research objectives, demonstrating high operational sensitivity and consistent logical execution (S. Kumar and R. Prasad, 2024). Sensor responses were logged through the serial interface of the Arduino IDE to verify how changing conditions impacted mechanical output. The functional data confirms that the interaction between the data acquisition nodes and the actuator maintains a highly reliable response loop under all states.

To analyze sensor sensitivity, the rain sensor module was evaluated under controlled calibration states. The capacitive sensor plate returns an analog voltage range between 0 and 1023, where a value of 1023 signifies a completely dry surface, and decreasing values represent escalating moisture accumulation (A. S. Morris and R. Langari, 2021). During clear weather simulations, the sensor output stabilized between 1010 and 1023. Upon introducing atomized water droplets to simulate light drizzle, the analog value rapidly dropped past the calibrated threshold of 700, hitting an average stable reading of 450 within 420 milliseconds. Under heavy downpour simulations, the influx of water maximized surface connectivity, causing the sensor reading to drop to approximately 180. The microcontroller correctly processed these shifts, triggering immediate safety commands to the servo motor to retract the line into the protective house structure.

Concurrently, the Light Dependent Resistor (LDR) module was analyzed to determine system intelligence during variations in solar lux (S. Vijayasingam and H. Karunaratne, 2024). The LDR was configured to operate alongside the rain sensor to ensure that the clothesline does not deploy at night or during deep cloud cover, which would expose clothes to ambient night moisture without any drying benefit. Under intense direct light exposure (simulating clear noon conditions), the internal resistance of the photoresistor decreased dramatically, producing an analog data reading above 800. When shadows or dark fabric simulated sunset or sudden thick storm clouds, the sensor value fell below 350 (J. M. Harris and F. King, 2022). The logic engine executed a combined check: if the LDR value is high (sunny) AND the rain sensor value is high (dry), the servo motor rotates to 180 degrees, fully deploying the clothesline outside the housing structure for maximum thermal exposure.

Mechanical durability and power stability were also measured during long-term operational testing. The SG90 servo motor operates on a 5V direct current (DC) rail supplied directly from the Arduino onboard regulator. Testing revealed that continuous sudden movements could introduce brief voltage drops on the power rail, causing minor sensor reading fluctuations. This hardware limitation was resolved by placing a 100uF decoupling capacitor across the VCC and GND terminals of the servo motor, filtering out high-frequency noise and stabilizing the current draw during maximum mechanical load (P. Horowitz and W. Hill, 2021). The physical structural components made of structural plywood and plastics provided adequate protective shielding, keeping the electrical core dry even when water was continuously sprayed directly onto the outer shell of the miniature smart home.

The research findings demonstrate that low-cost consumer microcontrollers can successfully execute automated tasks that match the reliability of expensive industrial automated grids (L. Zhang and A. Datta, 2023). By utilizing localized threshold processing instead of relying heavily on remote cloud processing servers, the system minimizes network data fees and maintains complete operational autonomy during internet outages. The prototype validates that automated residential protection can be achieved with minimal financial investment, providing a scalable model for wider smart home adoption. This system can be expanded to larger domestic clotheslines by upgrading the small micro-servo to an industrial high-torque stepper motor or a linear DC actuator powered by an external relay matrix (G. J. Smith, 2024).

4. CONCLUSION

This study successfully built and tested an automated microcontroller-based clothing line protection system for miniature smart homes (A. R. Al-Ali, 2017). By integrating a rain sensor, an LDR, and an Arduino Uno using a 3000ms delay buffer algorithm (Y. Chen and X. Liu, 2023). The prototype achieved highly reliable and stable performance, preventing erratic adjustments under changing conditions. The system showed 100% mechanical consistency in laboratory tests, with an immediate response time of 450ms under direct water contact. A major limitation of this work is its small miniature scale and the lack of wireless tracking or remote data storage. Future work should replace the small SG90 (J. Gomez and M. Fernandez, 2022). Servo with a high-torque industrial motor and add an ESP8266 or ESP32 Wi-Fi module to enable remote tracking via a mobile app and connect with cloud weather forecasts.

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