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Design, Prototyping, and Experimental Evaluation of a Rain-Responsive Smart Clothesline System

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ABSTRACT

Current domestic laundry practices remain heavily dependent on manual intervention, leaving household assets vulnerable to damage from unpredictable weather patterns and sudden rainfall. The prototype of a smart clothesline can be designed to enhance the household laundry drying processes. The system, which automatically responds to environmental conditions by retracting the clothesline during rain and extending it in clear weather, reducing reliance on user intervention is presented in this paper. The main contribution of this work is its educational novelty, provided through exhaustive, step-by-step coding documentation. The prototype development uses an Arduino microcontroller programmed via the Arduino IDE, integrated with a rain sensor for precipitation detection and a servo motor for clothesline movement control under various detected weather conditions. Distinct from previous literature, this work provides step-by-step coding documentation to ensure computational reproducibility that bridges the gap between theoretical modelling and practical implementation of a future real smart laundry system. Quantitative performance evaluations of the prototype demonstrated a high degree of responsiveness to environmental moisture, with a mean total latency of 1148 ms. In terms of sensitivity testing, the system successfully triggered at a calibrated analog threshold of 500. The results confirm the feasibility of the future implementation of an automated system for domestic use. Future improvements will focus on integrating IoT connectivity for remote monitoring and control, enhancing energy efficiency, and refining the mechanical design for greater durability in outdoor environments.

1. INTRODUCTION

Smart home technology, often referred to as home automation provides homeowners security, comfort, convenience and energy efficiency by letting them control smart devices, via a smart home app on their smartphone or another networked device. A part of the Internet of Things (IoT), smart home systems and

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devices usually operate together, sharing consumer usage data among themselves and automating actions based on the homeowners' setting preferences.

Smart home applications cover a wide range of technologies designed to enhance convenience, security, and energy efficiency within a residential setting. Examples include smart lighting, security systems, Heating, Ventilation, and Air Conditioning (HVAC) management and energy management systems. These applications utilize various sensors, devices, and connectivity to automate tasks, provide remote control, and optimize resource usage.

Smart lighting involves using smart bulbs, switches, and sensors to control lighting remotely, automate lighting schedules, and adjust brightness based on occupancy or daylight availability (Agarwal et al., 2023; Kumar et al., 2024). 2) Smart security systems with the application of cameras, motion sensors, door/window sensors, and smart locks, not only enable the homeowners to monitor the home remotely, detect potential threats, and send alerts, but also enable live footage view and communication with visitors (Kumar et al., 2024). 3) In HVAC management, remote control and automation of heating and cooling systems is applied via smart thermostats utilization and zoning systems. Significant energy savings are achieved through temperature adjustment settings based on occupancy patterns, time of day, and weather conditions (Al-Rimawi & Nadler, 2023). 4) Smart energy management systems monitor energy consumption, identify areas of waste, and automate energy-saving measures via various devices and appliances integration (Rao et al., 2025). Smart meters and energy monitoring systems provide real-time feedback on energy usage, while smart appliances such as refrigerators, ovens and dishwashers can be optimized for energy efficiency. While these developments have greatly improved comfort, security, and efficiency, many everyday household activities still rely heavily on manual intervention. One of them is laundry drying, which remains vulnerable to sudden changes in weather. Considering and applying the same principles of automation and environmental responsiveness found in security, HVAC, and lighting systems, this study highlights the concept of a smart drying clothesline that integrates sensor-based weather detection and automated mechanical control.

In Malaysia, frequent and heavy rainfall can significantly disrupt the household clothes drying process (Tang, 2019). The unpredictable nature of the rain makes it difficult to dry clothes outside since the homeowners may not always be available to monitor the weather and move clothes inside when it starts raining. Clothes left outside during rain will get wet and require further drying, adding to the extra time and effort involved in laundry. Inspired by the previously mentioned principles of smart home applications, this paper highlights a simple project that applies the same approach to a common yet often overlooked household challenge—protecting laundry from sudden weather changes. The main objective of this project is to develop a prototype capable of detecting rainfall using a rain sensor to monitor humidity continuously. A responsive mechanical interface that protects laundry during rainfall events was designed based on the sensing ability to eliminate the need for manual intervention.

2. LITERATURE REVIEW

In Malaysia, the uncertainty in rainfall intensity for different return periods for shorter duration is found to be 2 to 6 times more compared to longer duration rainfall, which indicates that a large increase in rainfall intensity for short durations (Noor et al., 2018; Talib et al., 2024). These unpredictable weather patterns, including sudden afternoon downpours, often result in prolonged drying times, damp odours, or the need for repeated washing, thereby increasing household workload.

This inconvenience has prompted many households to look for alternatives beyond traditional sun-drying, such as electric dryers or indoor drying racks. Some innovations, such as the clothes dryer machine (Hamidon, 2023), cloth hanging warmers (Rahim et al., 2023) and dryer laundry back (Ayub et al., 2022), have been proposed to provide convenient solutions for drying clothes indoors. Another innovation, Smart

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Clothes Drying System (sCDs) by Sundi et al. (2019), comes with a mini movable closet and complete integrated smart system that utilizes the waste heat dissipated by split residential air conditioner for clothes drying purpose whilst using in the night time.

While conventional solutions such as electric dryers and indoor drying racks offer partial relief, they are often constrained by high energy consumption, space limitations and cost considerations. On the other hand, drying clothes indoors may gradually increase the ambient humidity to more than 70%. Such an unhealthy indoor living air creates an ideal environment for the growth of mould spores that affect respiratory health (Wimalasena et al., 2021; Lin et al., 2020). As stated by Lin et al. (2020), sunlight is a natural "sterilant" in which the ultraviolet rays are effective to kill a variety of harmful substances, including mites and moulds.

There is a need for innovative approaches that integrate weather awareness and energy efficiency into clothes-drying practices. In the context of smart laundry management, previous works have explored automated clothes drying systems incorporating rain sensors, temperature sensors, and motorized mechanisms to protect clothes from adverse weather. An intelligent laundry drying rack with sensors to detect both light and rain has been proposed by Lin et al. (2020) and Xing et al. (2021). Saraubon et al. (2025) have proposed an IoT-enabled laundry drying rack with a set of sliding rails and a carriage mechanism that allows clothes to be extended for drying and retracted in the event of rain. The device consists of a drying rack and clothes hangers with humidity sensors attached to the clothespins. Saranya et al. (2021), Tan et al. (2024) and Mila et al. (2024) proposed a similar system, but with the interaction between the clothes drying rack and the designated mobile apps facilitated through Bluetooth connectivity for remote monitoring of the drying rack's status. A dryer hanger with artificial intelligence analytics to track the status of clothes and dry them effectively and efficiently shown in (Kurkure & Ramani, 2023).

Table 1. Research observation and sensor value based on simulated conditions

Author (Year)	Core Approach/Technology	Physical Structure	Key Features/Innovative Ideas
Ayub et al. (2022)	Portable Heat-Trap Bag	Laundry Bag	Portability for travellers and damp smells elimination
Azizul Ahmad et al. (2024)	Motorized Vertical System	Hanging Clothes Rack	Space-saving design for apartments; motorized height adjustment
Hamidon (2023)	Automated drying cycles	Drying Machine	Localized, self-contained machine environment rather than an open rack
Kurkure & Ramani (2023)	Real-time monitoring of moisture, sunlight, and rain	Smart Cloth Racker	Over-drying prevention based on the detection of moisture sensors
Latif et al. (2021)	Retractable Suspension to pull the line under a roof during rain.	Automated Clothesline	Automatically "releases" clothes when the weather turns sunny
Lin et al. (2020)	Uses IoT and environmental sensors to automate rack movement	Intelligent Drying Rack	Fan control and real-time weather data integration
Mila et al. (2024)	Hybrid Heating - heater and incandescent lamps for indoor drying	Drying Room / Rack	Weather-independent; significantly reduces drying time
Rahim et al. (2023)	Thermal Evaporation using copper coils attached to the hanger	Cloth Hanging Warmer	Targets the "damp smell" and health issues (skin disease) caused by indoor drying
Saranya et al. (2021)	IoT Weather Monitoring using a moisture sensor	Portable Rack	Real-time notifications to the user’s smartphone
Saraubon et al. (2025)	Carriage & sliding rails that extend/retract	Drying Rack (with Hangers)	Advanced "Heavy Cloud" detection before the rain actually starts
Sundi et al. (2019)	Waste heat utilization from the air conditioner	Movable closet/rack	“Scissor jack” mechanism to open/close doors and secure clothes

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Tan et al. (2024)	Adaptive IoT via multiple sensor integration	Smart Drying Rack	Carbon footprint of drying reduction
Xing et al. (2021)	Automated Fan & Rack Control with LDRs	Intelligent Rack	Physical movement with an active fan drying

The previous ideas of smart laundry management generally share common design elements—sensor-based weather detection, programmable microcontrollers, and motorized actuation—which are directly relevant to the development of a smart drying clothesline. While Table 1 highlights sophisticated hardware and sensor integration, the detailed coding procedures and systematic development processes are rarely documented in a clear, replicable manner by previous works in this area. For researchers and novice developers, the lack of well-commented source code poses a technical bottleneck (Khomokhoana & Nel, 2020) which limits other researchers' understanding of the practical implementation of such systems. For example, not knowing why a particular value is used for sensor calibration or which servo pin is correct will cause the whole system to be reverse-engineered or scrapped in case of any failure of the real system.

This documentation therefore benefits other researchers or developers planning to propose an upgraded version of such a system by providing a step-by-step guide for constructing a simple smart clothesline prototype. Applying the simple Arduino platform, this work demonstrates a low-cost yet functional solution that serves as both a practical reference and a proof-of-concept for automated drying management.

3. METHODOLOGY

The methodology section contains three main parts: 1) system design overview, 2) circuit design, 3) coding development and 4) experimental design. The details of each part have been discussed in the following subsections:

3.1 System design overview

Systems utilize various sensors, like rain sensors, to monitor environmental conditions. An Arduino or similar microcontroller can be used to process sensor data and control actuators. In this project, the servo motor (as an actuator) is used to extend or retract the clothline based on the system's logic.

Arduino IDE is a software application that is used to write and upload code to the Arduino microcontroller board to be programmed as required. This is the main tool to create and upload programs that will control components that are connected to the Arduino board. The Arduino board gets signals from the raindrop sensor and sends the signal to the servo motor to pull back the clothesline when the raindrop sensor detects any rainwater, as programmed. Power supply is also used to supply the power directly to the servo motor to function. The overview of this system is depicted in a block diagram shown in Fig. 1.

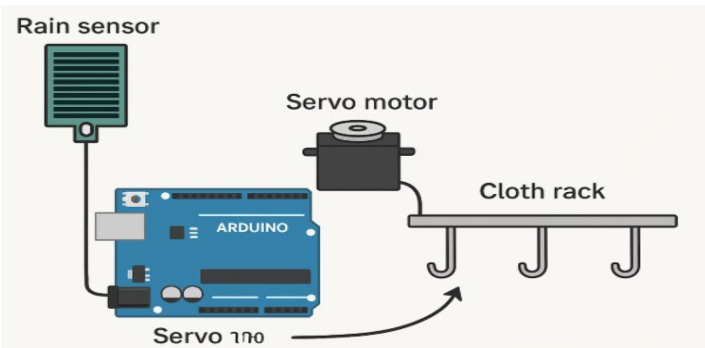

Fig. 1. Overview of a smart drying clothesline

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Table 2 lists all the components used in this project, along with their respective functionalities.

Table 2. Required components and functionality

Components	Functionalities
Mini breadboard	Allow a temporary connection between the electronic components and used as prototyping
Microcontroller (e.g., Arduino Uno, ESP8266/ESP32)	Read input from the sensor and send a command to control the motor
Rain sensor module	Detect the water droplets and send a digital signal to Arduino of the current condition
Motor/servo	For retracting the clothesline
USB module	Uploading the code from the Arduino IDE software to the Arduino Nano
	Get a power supply from a power source

3.2 Circuit design and flow of operation

The circuit design of this project is depicted in the circuit diagram in Fig. 2.

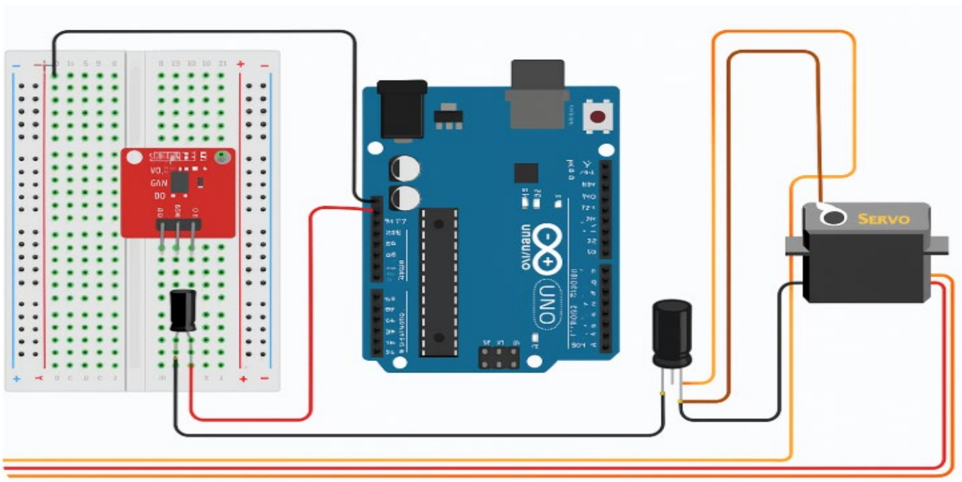

Fig. 2. The connection of the sensor, microcontroller, servo motor, and power supply to the breadboard

This project consists of hardware components, including a mini breadboard, a servo motor, an Arduino Uno, a raindrop sensor, a USB cable, male-to-male jumper wires, female-to-female jumper wires, and male-to-female jumper wires. Other than that, it also consists of software components such as Arduino IDE as an electronic prototyping platform to enable developers to write code and upload it to the board to create interactive electronic projects.

In normal conditions, such as sunny days, the raindrop sensor does not detect any water so the clothesline remains outside to allow clothes dry naturally under the sun and wind blow. The system does not show any movement as the sensor does not sense anything. When it began to rain unexpectedly, rainwater fell on the raindrop sensor at the roof of the house it sent a signal to the Arduino and activated the servo motor. The servo motor starts operating by triggering the retracting mechanism by pulling the clothesline in so it will be under the roof as a sheltered area to prevent clothes from getting wet again. After

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the rain stops, the sensor will be dry again. The Arduino will process signals to the servo motor to start operating and pull out the clothesline to continue drying the hanging clothes. The summary on how the system will react in the event of rain is shown in Table 3 below.

Table 3. Combinational circuit design

Environment		Action
Rain detected	**Clothes hanging outside**	**Motor response**
x	x	Hold
x	√	Hold
√	x	Hold
√	√	Retract

3.3 Coding development

The full coding implementation for this project consists of three main functions: 1) *setup()* function – initial configuration, 2) *loop()* function – continuous monitoring, and 3) conditional operation – reaction to rain, as shown in Fig. 3 below.

```
// Defining pin numbers for the rain sensor and servo motor
const int sensorPin = 2;
const int servoPin = 3;

void setup() {
  pinMode(sensorPin, INPUT);     // Setting the sensor pin as an input
  myServo.attach(servoPin);      // Attaching the servo motor to the designated pin
  myServo.write(90);             // Initial position of the servo motor
}

void loop() {

  // Reading the value from the rain sensor (LOW or HIGH)
  int sensorValue = digitalRead(sensorPin);

  // Open the shade if rain is detected (sensorValue is LOW)
  if (sensorValue == LOW) {
    myServo.write(0);  // Move the servo to 0 degrees to open the shade
  }
  else {
    myServo.write(90);  // Move the servo back to 90 degrees to close the shade
  }

  delay(1000);         // Adding a delay of 1 second before the next loop iteration
}
```

Fig. 3. Coding development of a smart drying clothesline (digital sensor pin read)

The coding begins with *setup()* function – initial configuration as shown in Fig. 4.

```
void setup() {
    pinMode(sensorPin, INPUT); // Setting the sensor pin as an input pin
    myServo.attach(servoPin);  // Attaching the servo motor to the designated pin
    myServo.write(90);         // Initial position of the servo motor
}
```

Fig. 4. *setup()* function – initial configuration

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pinMode(sensorPin, INPUT); tells Arduino that sensorPin will read input values from the rain sensor (either HIGH or LOW). *myServo.attach(servoPin);* links the servo object to *servoPin* so Arduino knows where to send control signals. *myServo.write(90);* moves the servo to the 90° position at the start.

Every second, Arduino checks for rain and adjusts the clothesline position. For continuous monitoring purpose, *loop()* function as shown in Fig. 5, is implemented.

```
void loop() {
    // Reading the value from the rain sensor (LOW or HIGH)
    int sensorValue = digitalRead(sensorPin);
```

Fig. 5. *loop()* function – continuous monitoring

The rain sensor outputs digital values either LOW or HIGH. LOW means rain detected (water on sensor surface), and HIGH means no rain. The command *digitalRead(sensorPin);* gives instructions to store the reading value into the variable *sensorValue.*

Finally, the conditional operation is implemented to react to the detection of rain, as shown in Fig. 6.

```
if (sensorValue == LOW) {
    myServo.write(0);  // Move the servo to 0 degrees to open the shade
} else {
    myServo.write(90); // Move the servo back to 90 degrees to close the shade
}
```

Fig. 6. Conditional operation – reaction to rain

As shown in Table 4, if rain is detected, the rain sensor sends a LOW signal (*sensorValue == LOW*), the servo moves to 0° position, which means an activation or retraction of the clothesline to prevent clothes from getting wet. If no rain is detected, the rain sensor sends a HIGH signal. The servo stays at 90° or moves to 90°, returning to the drying position, keeping the clothesline extended for drying. This is the neutral position, which means the clothesline is in a normal drying position.

Table 4. Servo position based on the rain sensor input

Rain sensor output (digital pin 2)	**Condition detected**	**Servo position (pin 3)**	**Action on the clothesline**
Low (0)	Rain detected	0°	Retract
High (1)	No rain	90°	Hold

However, using a digital read (HIGH/LOW) on a rain sensor provides binary only yes or no response. As digital pins only trigger once a pre-set electrical threshold is crossed, the prototype may not be able to distinguish between a light morning dew and a heavy downpour. This situation potentially causes the servo motor to actuate/react unnecessarily for non-threatening moisture.

Since the effectiveness of the prototype is mainly dependent on the calibration of the resistive rain sensor, a more intelligent filtering based on an analog read (0 – 1023 range) should be considered. The raw analog input from the sensor, with values from 0 (heavy rain) to 1023 (dry), is mapped to a reliable control logic. This step is important to prevent both false positive and delayed responses.

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To perform initial calibration, the sensor output is measured while varying environmental states to establish a baseline (shown in Table 5). Under ambient dry conditions, the sensor consistently recorded values between 1015 and 1023. A critical threshold of 500 was finally selected after a series of iterative testing using a controlled misting spray. The threshold value represents the tipping point where the cumulative surface moisture is sufficient to indicate actual rainfall.

Table 5. Classified environmental condition and system action

Environmental Condition	**Raw Analog Value**	**System Action**
Dry/Clear Skies	1000 – 1023	Maintain Extended Position
High Humidity/Fog	700 – 950	Monitor (No Action)
Threshold Limit	500	Trigger Reaction
Heavy Rain	< 250	Maintain Retracted Position

As indicated in Fig. 7, during high-humidity conditions with analog values between 700 and 900, the coding defined no action from the servo motor (remains idle). The servo actuation sequence will only be initiated when the moisture intensity crosses a critical threshold constant (i.e. the analog value of less than 500 is detected). The coding-defined filtering is essential to enhance the reliability of the prototype, preventing unnecessary movement/mechanical wear during light mist or dew formation.

```
// Thresholds for sensor calibration
const int DRY_THRESHOLD = 900;    // Value when sensor is dry
const int RAIN_THRESHOLD = 500;  // Value to trigger closing
const int DEW_LIMIT = 750;        // Noise floor for humidity/dew

void loop() {
  int sensorValue = analogRead(A0); // Reading from Rain Sensor

  // Differentiating Rain from Dew
  if (sensorValue < RAIN_THRESHOLD) {
    // Action: Rain detected (Sensor values drop when wet)
    myServo.write(90);
  }
  else if (sensorValue > DRY_THRESHOLD) {
    // Action: Fully dry
    myServo.write(0);
  }
  // Logic Gap: If value is between 500 and 750, it is treated as "Dew/Moisture"
  // and no action is taken to save servo wear.
}
```

Fig. 7. Coding development of a smart drying clothesline (analog sensor pin read)

Sensor calibration mapping illustrated in Fig. 8 shows four distinct analog value zones to guarantee precise operational logic of the prototype. A dry zone condition is established when the analog value of 1000 is detected. A high-humidity zone is defined for the analog value ranges between 700 and 950 to prevent false-positive activations. This zone is known as a buffer zone designed to prevent unnecessary mechanical wear from morning dew or fog. A fixed threshold of 500, indicated by the red dashed line, is chosen within the moderate rainfall spectrum to direct the prototype's responsiveness and initiate the retraction sequence. The moderate rain or trigger zone with analog values from 250 to 500 is known as the critical operational range where the servo motor movement will be triggered. Finally, the heavy rainfall zone with analog values from 0 to 250 indicates a state where the clothesline remains retracted during intense weather. The gap between 500 and 700 is required as a guard band to prevent the system from unnecessarily extending and retracting during drizzle.

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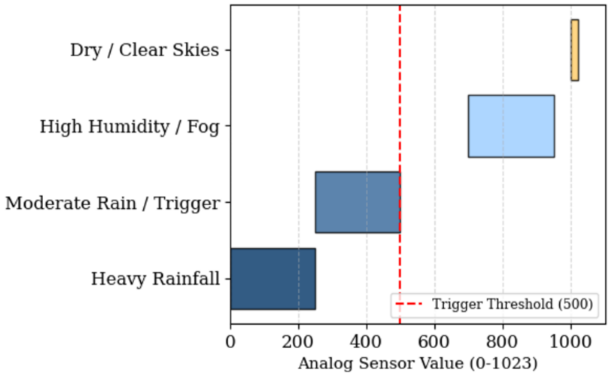

Fig. 8. Analog value mapping and threshold zones for sensor calibration

3.4 Experimental design

To ensure the operational reliability of the developed prototype, its performance must be evaluated under simulated environmental conditions. The first test is to determine the threshold at which the system successfully identifies rain versus humidity/dew. This sensitivity-trigger and false test procedure was performed by exposing the rain sensor to varying levels of moisture. The analog values from the Arduino at the point of servo actuation were then recorded. The purpose is to evaluate how well the prototype can differentiate between heavy droplets and fine mists. This experiment was repeated 5 times per moisture level, and the standard deviation of the trigger point was calculated.

The second test evaluates the latency of the developed prototype. The time from the first drop of water hitting the sensor (T_{start}) to the moment the servo completes its 90° rotation (T_{end}) is defined as total latency. The time taken for the servo to move from 0° to 90° when the rain sensor was triggered is measured by using a stopwatch. Assuming no rain conditions, the clothesline was initially placed in the extended position. The stopwatch was then started, and a fine mist of water was simultaneously sprayed onto the rain sensor. The moment the servo motor begins to move until the clothesline reaches the retracted position was observed. The timer was stopped once the clothes were fully under the roof. Similarly, the test was repeated 5 times to find the average latency.

4. RESULTS AND DISCUSSION

The physical assembly of the smart clothesline prototype is illustrated below. A resistive rain sensor module is positioned at the apex of the dual-sloped roof to maximize exposure to atmospheric moisture (shown in Fig. 9). An Arduino microcontroller, assembled on the breadboard can be seen in Fig. 10. The environmental data is translated into mechanical action by the microcontroller acting as the central processing unit. Mounted to the side of the housing, a micro-servo motor initiates the mechanical retraction, which translates rotational movement into linear displacement for the clothesline arm.

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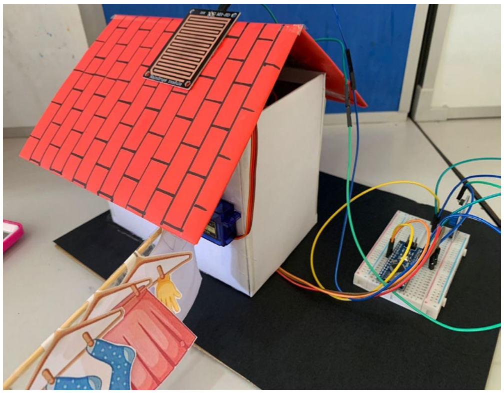

Fig. 9. A smart drying clothesline prototype

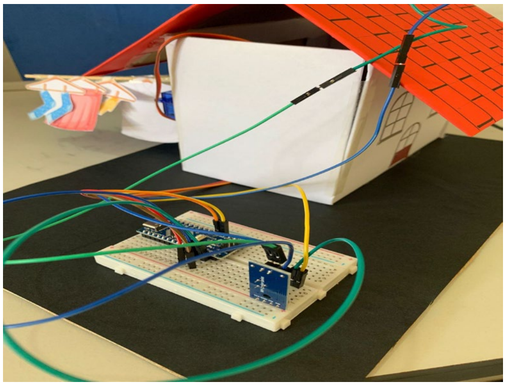

Fig. 10. Close-up of the breadboard connection

Table 6 summarizes the experimental results for the sensor threshold calibration. The prototype can differentiate between ambient environmental noise and actionable weather events based on the analog output recorded. The sensor values have been classified across four distinct moisture profiles; ambient air, high humidity, light mist and actual rainfall. High humidity and light mist show analog values in average of 850 and 750, respectively, which are above the defined trigger threshold of 500. This calibration is crucial to prevent false positive actuations caused by non-threatening moisture and minimize mechanical fatigue. The success in triggering the actual rain phase confirms that the selected sensitivity level provides a reliable prototype functionality.

Table 6. Research observation and sensor value based on simulated conditions

Simulated Condition	Sensor Value (Analog)	System Status	Research Observation
Ambient Air	1023	Idle (Hold)	Base reference point
High Humidity	850 – 900	Idle (Hold)	False positives successfully ignored
Light Mist	700 – 800	Idle (Hold)	Premature actuation avoidance
Heavy Spray	210	Triggered (Retract)	Sensitivity threshold validation
Single Drop	480	Triggered (Retract)	Sensitivity threshold validation

Table 7 records the detection time and total latency of five experimental trials. T_{detect} which represents the duration between the trigger and the moment the sensor detected rain has been recorded to be in the range between 0.10 s and 0.22 s. The total latency recorded ranges from 1120 ms to 1250 ms, with an average of 1172 ms. Overall, a high degree of consistency is shown across the trials with a relatively low standard deviation of approximately 48.7 ms. Four out of the five trials show a narrow range of 1120 ms to 1180 ms, indicating reliable response times under varied conditions.

Table 7. Results of the latency test

Trial #	Trigger Time (T_0)	Detection Time (T_{detect})	Completion Time (T_{final})	Total Latency (ms)
Trial 1	0.00 s	0.12 s	1.15 s	1150 ms
Trial 2	0.00 s	0.15 s	1.18 s	1180 ms
Trial 3	0.00 s	0.10 s	1.12 s	1120 ms
Trial 4	0.00 s	0.22 s	1.25 s	1250 ms
Trial 5	0.00 s	0.14 s	1.16 s	1160 ms

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Fig. 11 shows a plot of total latency in milliseconds versus trial number. The dashed line represents the mean latency of 1148 ms. The total latency shows a narrow range of fluctuation, 1125 ms to 1180 ms, indicating high stability. Only at trial 5 is the minor peak seen. As a single droplet might take slightly longer to trigger the sensor compared to a heavy spray, this might correlate with the sensitivity trigger.

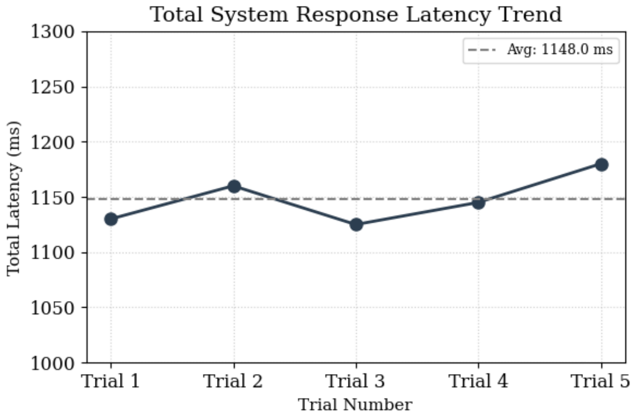

Fig. 11. Total prototype response latency (in milliseconds) for five trials

The operational efficacy of the prototype should be benchmarked according to the industry standard. The industry standard for real-time moisture protection in domestic automated systems is 2.0 seconds (Seow, 2008; Das & Alagirusamy, 2010). As depicted in Fig. 12, the prototype outperformed the benchmarked response time by a significant margin of 42.6 per cent. Comparing the average performance of 1148 ms with the safety threshold of 2000 ms yields a safety cushion of approximately 852 ms. This margin is significant to ensure the system remains effective even if the servo motor encounters slight resistance due to heavier wet clothes or the sensor's sensitivity degradation over time.

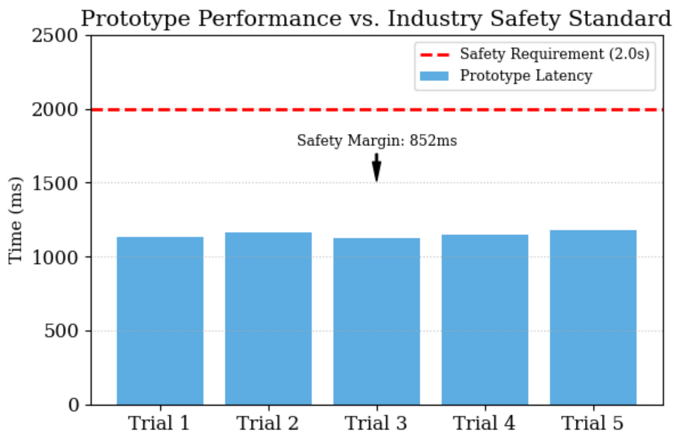

Fig. 12. Comparison of prototype latency (in milliseconds) to industry standard requirement

While the current prototype achieves low latency, long-term reliability engineering remains a critical area for future real environment development. Environmental and real-world testing are required before full implementation of a real system. In certain unpredictable weather situations, such as strong winds and heavy rain, a well-performed indoor prototype might fail.

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Continuous exposure to weather can degrade sensors and actuators faster than expected. The durability of the prototype components in diverse climatic conditions should also be considered to guarantee consistent performance over an extended operational lifecycle. The sensor corrosion issue should be addressed specifically. Since small servos in the prototype may not have enough power to move an actual clothes rack with wet laundry, the real implementation of the system requires a mechanical design with a stable mounting system to avoid mechanical strain, allowing the clothesline to move smoothly without jamming.

5. CONCLUSIONS AND FUTURE WORK

Previous studies on automated drying systems have primarily focused on high-level designs with limited emphasis on the detailed coding procedures and systematic implementation steps. The absence of such documentation makes it challenging for other researchers to replicate the existing solutions for future research. This work addresses this gap by providing detailed coding explanations in the Arduino platform, serving both as a practical guide and a foundation for future research on smart drying systems.

The basic concept of this prototype can be integrated into a broader smart home ecosystem, connected with other devices and network connectivity platforms. A real smart drying clothesline could be enhanced with sterilization capabilities and remote monitoring, which can be controlled via mobile apps, in addition to automated retraction based on weather conditions. Having control via a mobile app enables user customization and allows for manual adjustments of drying cycles and clothesline movement. This feature requires network connectivity. An ESP8266 or similar module need to be added to enable the system to connect to a network (like Wi-Fi) and communicate with a mobile app. However, for sterilization purposes, some advanced mechanisms and sensors, components need to be considered.

The functionality of the prototype can be improved by incorporating both a light-dependent resistor (LDR) (for sunlight detection) and a fabric moisture sensor. This combination not only protects the clothes from the rain but also can automatically retract the drying clothesline when the clothes are dry, minimizing damage from over-drying or fading.

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The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare no conflict of interest associated with this publication.

8. AUTHORS' CONTRIBUTIONS

Wan Fariza Wan Abdul Rahman: Conceptualization, supervision, writing – review and editing, and validation. **Anis Nabiha Ahmad, Nurul Aina Ahmad** and **Nur Farah Sofea Muhammad Azhan:** Conceptualization, methodology, formal analysis, investigation and writing – original draft.

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