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Clothes Drying System Using Iot, Ai And Renewable Energy

Integrating IoT, AI, and Renewable Energy in Domestic Automation

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Abstract: Outdoor clothes drying is common, but our plans are frequently ruined when unexpected rain dampens our laundry. This everyday experience inspired the development of a smart clothesline system that leverages the Internet of Things (IoT), artificial intelligence (AI), and sustainable energy. The smart clothesline system is comprised of a NodeMCU microcontroller, rain and humidity sensors, temperature sensors, light sensors, and a wind sensor. The sensor measurements are continuously uploaded to a cloud server, and from there, the system displays a simple web dashboard that tracks the current conditions of the IoT-enabled clothesline system from anywhere on any device. In addition to being able to tell when it is raining, the smart clothesline system uses free weather API data combined with the local sensors to predict rainfall 15–30 minutes in advance through a lightweight decision model. When rain is detected or predicted, the servo motor retracts the clothesline rod automatically by moving the clothesline garments under a protective roof, and at the same time, preventing the fabrics from getting wet. Additionally, to ensure this system is sustainable, it uses a small solar panel and a rechargeable battery pack. We are pleased to offer this low-cost, environmentally friendly, reliable home automation system that minimizes the manual effort of managing our laundry while minimizing dependency on grid electricity. The system illustrates the possible amalgamation of IoT, AI, and solar in a practical smart home application.

Index Terms - Smart drying system, NodeMCU, rain prediction, IoT, solar power, home automation, servo motor

I. INTRODUCTION

Hanging clothes to dry on a clothesline is probably one of the most common practices in households across the country, especially in the sunniest states. This is because it is a simple, free and natural method to dry clothes. However, on the flip side, it can be very problematic for a variety of reasons: rain, wind and other weather conditions can halt laundry drying perfectly and unexpectedly, leaving the laundry wet and inconvenient, wasted time and energy. We can be ready to tackle to rain, but checking the weather and pulling in clothes regularly is inconvenient, erroneous habits for our never ending list of household chores. It calls for a better solution, where clothes can hang dry safely for a period of time, rain or not, without having to constantly inspect the clothes.

In recent years, because of the Internet of Things (IoT) in household devices, the mechanization surveillance of smart devices has made household chores more automated and responsive to changes in conditions. Through the assessment of sensor data, microcontrollers, and wireless transmission, IoT systems can assess real-time conditions and take action based on conditions without human input. When IoT systems combine with Artificial Intelligence (AI), an IoT system can proactively learn, analyze, and assess changes in conditions rather than reacting to the changes. With AI, an IoT can collect sensor data and external weather reports to predict the rain and dry clothes. This is a powerful capability, with only a minor delay in the ability to safely protect drying clothes from rain at all times.

Previous works have focused on a number of automated clothesline systems, primarily operating on rain sensors/markers to identify the presence of water droplets and retract the clothesline mechanical system. These automated clothesline systems certainly provide great utility. However, they are limited in several ways; they only act once rain is detected, which means rain has already began, they generally offer no online monitoring, and they universally require electricity from the grid to operate. None of the current approaches incorporate other weather parameters, such as humidity, temperature, wind, and cloud cover, that could be considered part of a systematic rainfall indication system. In addition, many of the automated clothesline systems are not designed to be energy-efficient and typically do not include energy generated from sustainable sources to be used for long-duration and sustainable smart homes.

To ameliorate existing solutions and limitations, we provide a new weather aware clothes drying mechanism that incorporates IoT, AI, and renewable energy. Our implementation uses a NodeMCU microcontroller with Wi-Fi, and is connected to a multiple sensor set containing temperature, humidity, rain, light, and wind sensors. Each of the sensors collect real-time environmental data which we upload to a cloud-based server, and provide a lightweight PHP interface. A streamlined web dashboard for remote condition monitoring is manageable from any device including a mobile device. The most unique aspect of the system is the inclusion of AI-assisted rain prediction. Rather than only using a rain sensor, the system uses local sensors connected to an online weather API. An analytical decision rule model is used to estimate the likelihood of rain in the upcoming 15 to 30 minutes. When the system detects rain or is able to predict rain it automatically uses a servo motor to retract the rod and place the clothes under a sheltered area prior to getting wet.

The advances in automation and intelligence are enhanced with sustainability, as the entire system is powered by a small solar panel, charge controller and rechargeable battery pack. It does not rely on the electrical grid to operate the system. This system is sustainable, environmentally friendly, and affordable. This system would be suitable for households located in areas where power cuts happen frequently, or electricity supply is poor.

II. LITERATURE REVIEW

The possibility of automating everyday household chores through sensor-based systems has become prominent in the last ten years. With regard to automating clothes drying, the focus has primarily been on reducing work and avoiding inconvenience when unexpected rain occurs. The first attempts to automate clothes lines primarily employed the reactive rain sensor which simply detected water droplets and mechanically retracted the clothesline. For example, IDE, Iqbal et al., and Al-Mumaan et al. presented microcontroller based systems where when a rainwater droplet was detected a motor pulled clothes under a covered area. These approaches were functional, but only exhibited a reactive response to rain and did not offer any rainfall prediction, so their effectiveness in preventing laundry to become wet was limited.

Now, with the advances of the IoT, the realm of clothesline automation has expanded the operational parameters to multi-sensor fusion systems. A few systems have even been developed to combine humidity, temperature, and light sensor technology with rain sensors to further assess environmental characteristics. These approaches offer the advantage of additional environmental context beyond a rain event, however, they still only improved upon the rain detection capability.

Nonetheless, the majority of implementations were limited to local automation and did not incorporate remote monitoring capabilities or integration with online services. The lack of cloud integration meant that users were unable to monitor weather information, as well as the status of the system, in real-time on their mobile devices. This reduced the overall usefulness of these types of systems in a contemporary (fully) smart home.

A handful of researchers have attempted to incorporate wireless communication to enable cranes to monitor the clothesline systems remotely. These GSM modules or Wi-Fi microcontroller solutions enabled users to obtain a notification when rainfall was detected. While these methods were improvements regarding user convenience, the principle control methods still relied on the detection of rain. Once the rain was detected, the clothesline systems would only protect the clothes once rain actually started which still meant that clothes could become partially wet during an average reaction time. In addition, the vast majority of these designs used traditional means of electricity which raised additional questions of energy efficiency and longer term sustainability.

Some research has begun to explore the role of predictions to support weather responsive automation. Recently, cloud systems have made use of weather predictions from sources online to notify users of potential rain.

While these systems showed a significant development step towards predictive automation, most rely solely on externally sourced weather data, and inherently fail to include feedback from local sensors. This dependence on third-party forecasting reduces the system's ability to respond and estimate accurately, particularly in areas where micro-climatic variations are likely to diverge from the general area ST-1.

Based on the literature review, it appears there are a few shortcomings of current clothesline automation systems. Most solutions adopt either a purely direct detection of rain, or are channeled solely on external forecast models that do not equally leverage both sources of data in a smart manner. All systems reviewed are without lightweight AI models that restrict proactive and reliable prediction abilities. The energy efficiency of these systems has also been poorly researched, with limited work focusing on renewable power sources (i.e., solar panels) for sustainable operations. Overall, there is a clear gap and need for research in evolving a design for a low-cost, eco-friendly, intelligent clothes drying system that is transferable to the IoT, based on sensors, cloud-based AI prediction, and along with a renewable energy source, developed as a singular holistic framework.

III. SYSTEM DESIGN

The proposed method of drying clothes, while aware of the weather, creates integration of sensing, control, prediction, actuation, and renewable energy into one IoT system. The overall system can be represented in a block diagram as having five major system Loop components; a sensing unit (input layer), the control and communications unit, the prediction and decision layer, an actuation layer, and the power management unit. These subsystems all communicate and collaborate in a trusted way with the central microcontroller, and the cloud server to achieve a generally reliable and autonomous system.

The sensing unit represents the initial layer about which the overall system would orient itself. In terms of name, the sensing unit incorporates a DHT11/DHT22 sensor that provides temperature and humidity readings, a rain sensor to measure raindrops, an LDR (Light Dependent Resistor) sensor to measure ambient light, and a wind speed sensor to measure any wind gusts that may accompany rain. These sensors provide complete information on the local weather situation in real time. The information from the sensors not only generates an immediate response but when coupled with external forecasts, can also provide predictive decisions.

The control and communications module is implemented using the NodeMCU microcontroller and the ESP8266 Wifi module. Using Wifi, NodeMCU runs continuous loops to collect raw data from the sensors, process it locally, and wirelessly upload the data to a cloud server. Wi-Fi as a communication protocol keeps the system connected to the internet, allowing the data to be stored in a remote database and the data displayed in a responsive web dashboard developed in PHP. The PHP web dashboard is accessible from any device connected to the internet. Thus, the user can observe the weather parameters and the status of the system, whether they are at home or away.

The prediction and decision module combines local sensor readings and online-weather data from a free meteorological API. A small AI model, implemented as decision rules in PHP, considers both sensor data and online weather information, and estimates the chance of rain in the next 15-30 minutes. The hybrid approach of local real-time sensing together with higher accuracy weather forecasts from a cloud-based platform improved predictive accuracy and employed proactive environmental responses instead of only reactive responses when rain was detected. The decision output is then sent back to the microcontroller to initiate the specific control actions.

The actuation mechanism allows for physical movement of clothes under shelter when rain is encountered or predicted. The way this actuation works is simply with a servo motor which is connected to a movable rod that clothes are hung on. When Node MCU sends the control signal, the servo motor turns the rod and slides the clothes from the open drying position into a sheltered position under the roof. The actuation process is not overly complicated; the purpose is to preserve clothes under sudden rain, and the clothes can be quickly relocated without requiring any human involvement. The state of the clothes (drying or retracted) is logged in the cloud database to monitor and gather information regarding the access of the system.

The power management unit provides energy autonomy and sustainable energy for the system. It consists of a small solar panel, a charge controller, and a rechargeable battery pack. The solar panel captures energy during the day while the charge controller makes sure power flow into the battery is controlled and prevents overcharging the battery or deeply discharging the battery. The energy which is stored in the battery is provided to the Node MCU, the sensors, and the servo motor; details are similar, so that it is guaranteed that the system remains operational even in cloudy weather or at times, during the evening or night season. Thus, the solar panel is considered renewable energy, so this style of system is more environmentally friendly than powered through poor grid supplies. The solution can be employed in rural and urban areas where reliable electricity may not always be provided from certain locations.

IV. METHODOLOGY

The methodology that was developed to realize the proposed weather-aware clothes drying mechanism makes systematic combinations of hardware, software, and communication technology to achieve automation. The overall workflow examines data acquisition from multiple sensors, communicates to the cloud server, performs predictive analytics using an AI model, and implements actuation. The process is executed in real-time and is always powered on using solar power for power management.

The first stage of the workflow represents data acquisition, where environmental parameters are recorded from a set of interconnected sensors. The DHT11/DHT22 sensor logs ambient temperature and relative humidity; the rain sensor detects droplets of water; the LDR measures the light level surrounding the system; and the wind sensor captures wind speed. The sensors were connected to a NodeMCU microcontroller, which was to serve as the primary receiver for the sampled data inputs and communicate to the second half of the system. The sensors are read to obtain the current state on a schedule to ensure the system is using the most up to date meteorological data that is available.

The second stage regards data transmission and storage. After collection, the NodeMCU will format the sensor data and transfer it wirelessly using its integrated Wi-Fi module. The data is uploaded to a cloud hosted server that runs PHP scripts and stores the data in a MySQL database. This cloud structure provides permanent storage of environmental conditions and is capable of real-time viewing through a custom web dashboard. This dashboard is mobile-friendly and can be viewed from any internet-connected device, regardless of location, allowing users to check weather conditions and system health from anywhere.

The third stage of the workflow is rain prediction/decsion-making as the intelligent heart of the system. The system not only detects rain through the sensor, but it also acquires weather information and data through an external weather API such as the ",by extracting externally defined parameters (temperature, humidity, cloud cover, precipitation, and wind speed). The values provided by the weather API are integrated with the local sensor data and processed through a PHP rule-based artificial intelligence model in order to assess the possibility of rain in the next 15 to 30 minutes. The model conditions considered include high humidity, low light, increased wind speed, and heavy cloud cover.

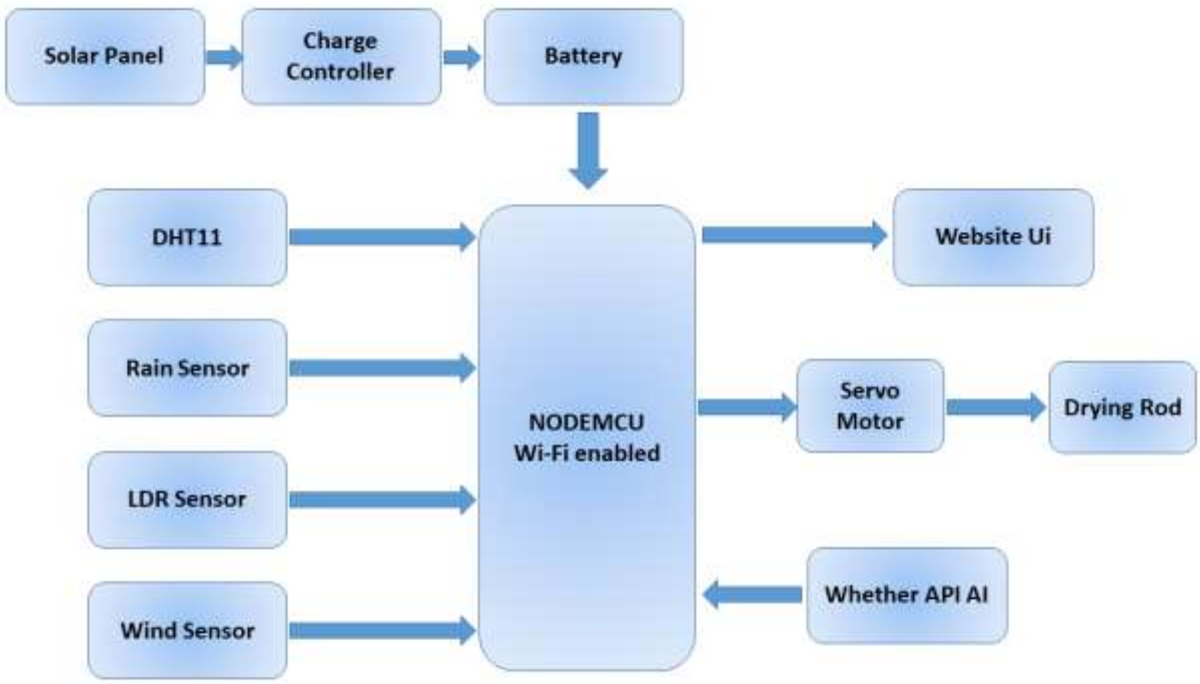
The fourth stage is actuation and control, where decisions become real actions. If the system detects or predicts rainfall, then the NodeMCU sends a control signal to the servo motor mechanically connected to the clothesline rod. When the motor receives the signal, it will rotate the rod with the attached clothes to switch clothes from an exposed drying position into a sheltered position. Eventually when the weather stabilizes, the system can return the clothesline back to a drying position. The activities of the motor are logged into a cloud database, which ensures that the web dashboard represents the current operational state of the actuator in real-time.

The last stage is power management, which ensures a disruption-free process for when the system is running. Energy is captured from the sun during the day through a solar panel and the energy is send to a rechargeable battery through a charge controller. The battery can then send energy to the NodeMCU, the sensors, and the servo motor. This allows for the system to run to maintain its operation as normal. The system should be dependent on the collected energy to power the components even at night time or if it cannot collect energy for an extended period of cloudy conditions. Incorporating energy from renewable systems increases production, spares costs related to energy usage, and reduces reliance on standard forms of electricity.

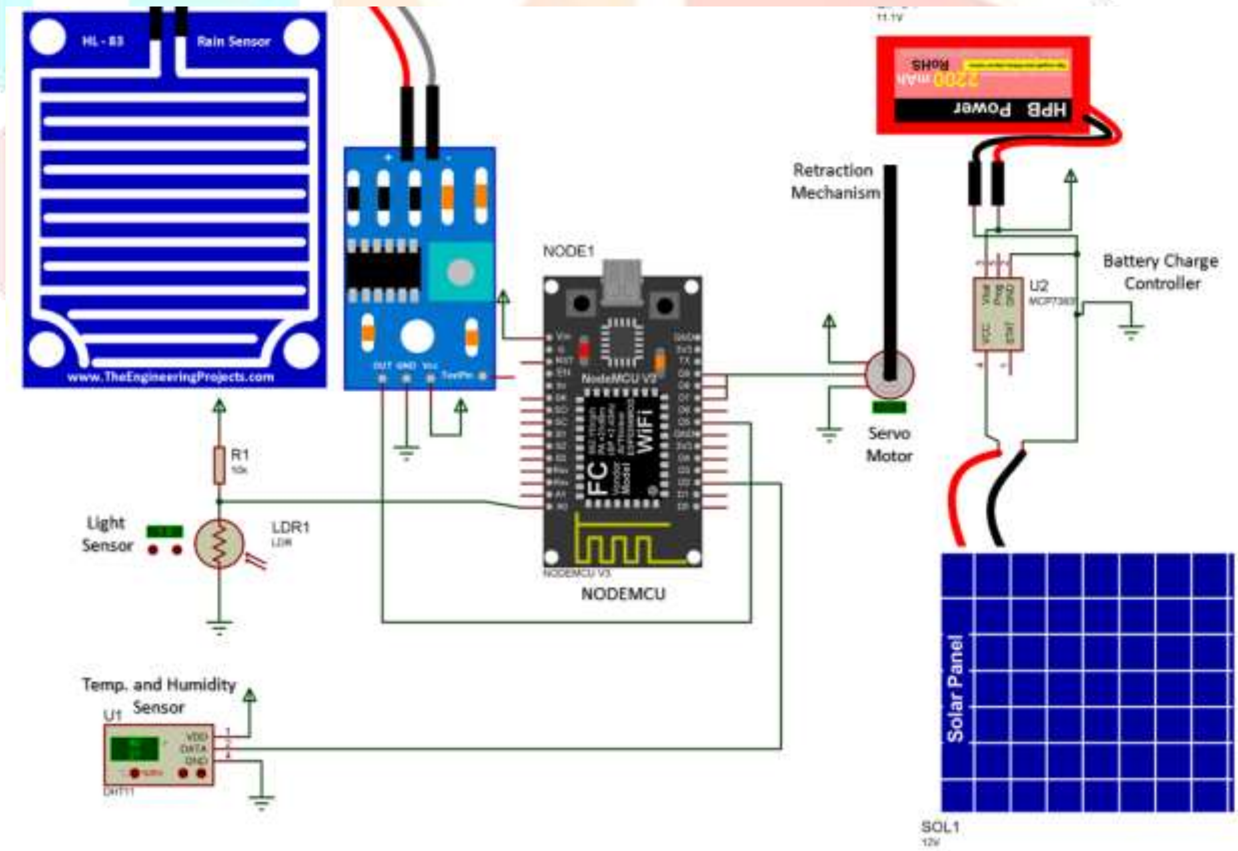
Through this multi-stage methodology, the system achieves a seamless workflow starting from environmental sensing, data communication, predictive analysis, and automated actuation, all while remaining energy-autonomous. The methodology ensures that the solution is intelligent, eco-friendly, and practical for household use, thereby addressing the limitations of earlier designs that relied solely on reactive rain detection or grid power.

V. IMPLEMENTATION

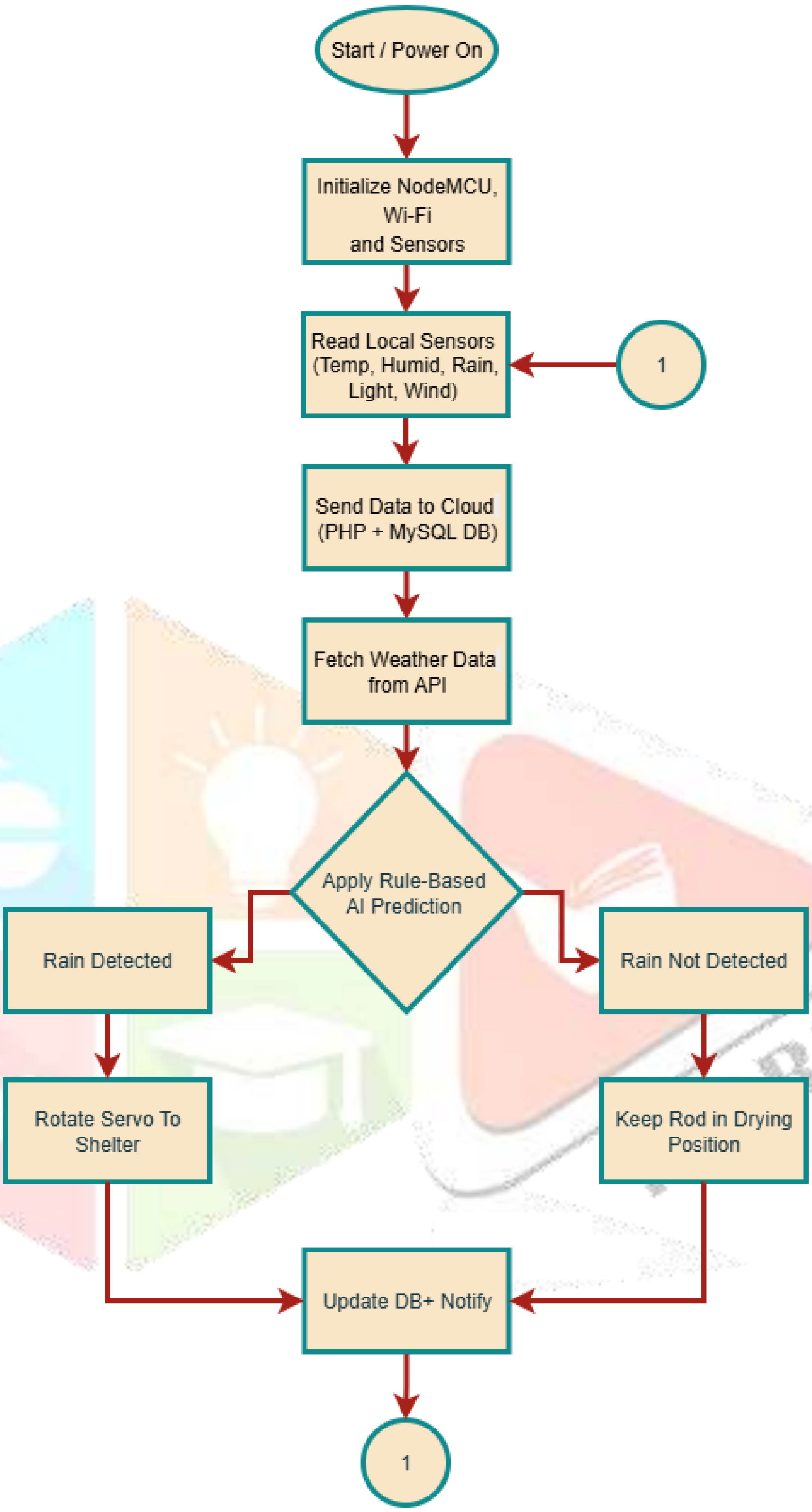
4.1 Block Diagram



4.2 Circuit Diagram



4.2 Flow Chart



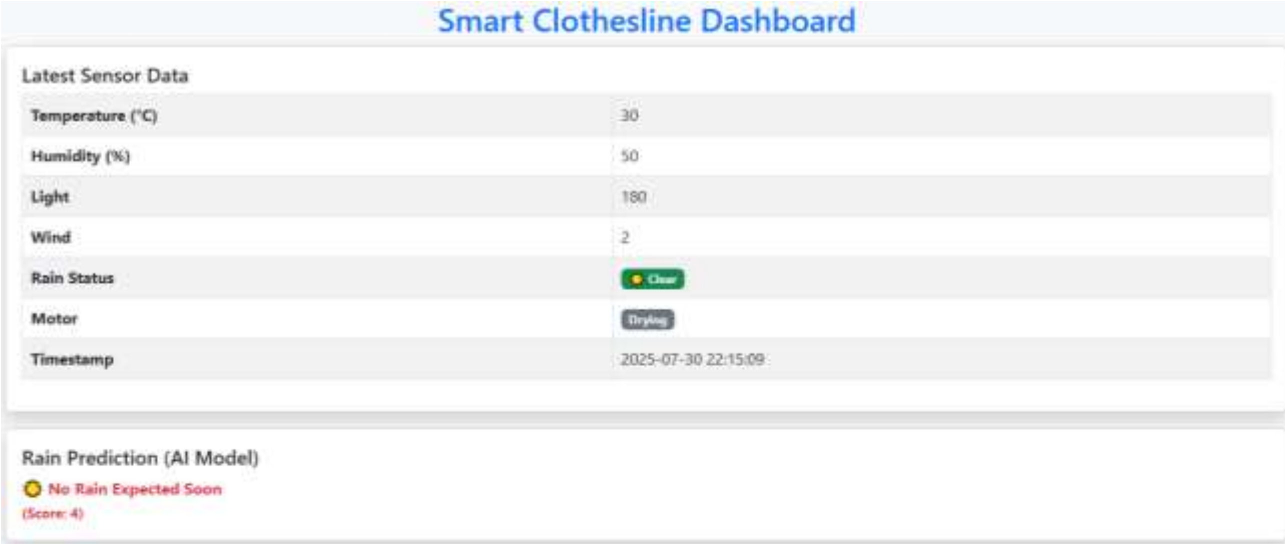
The process begins with system startup when the NodeMCU connects to Wi-Fi and initializes all sensor modules. After that, the microcontroller monitors the data from the temperature sensor, humidity sensor, light sensor, wind sensor, and rain sensor.

The data collected from the sensors is uploaded to the cloud server and then displayed on the web dashboard for user monitoring, while the NodeMCU also retrieves external API information about the weather. The weather conditions from both the local sensors and the external API value will go through a rule-based AI model that determines the likelihood of rain in the next 15–30 minutes.

When there is rain detected or expected, the decision module sends a command to the servo motor to retract the clothesline rod to the sheltered position, and this action will be logged and shown on the cloud dashboard too. When there is no rain detected or expected, the clothesline will remain in the drying position. The process will then return to the start and continue monitoring the weather conditions and making new decisions in real-time.

The flow chart accurately illustrates the logical procedural workflow of the system, message flow from initialization, sensing, and data transmission to prediction, decision-making, action, and feedback.

4.3 Web UI



VI. RESULTS & DISCUSSION

The weather-aware clothes drying system was implemented and thoroughly field tested in the real world context, the functionality of the system was evaluated through real-world use. The system was able to incorporate sensing, prediction, cloud access, and actuation, and the system operated consistently throughout all trials. The results for the field deployment were evaluated in terms of system responsiveness, accuracy of rain prediction, automation efficiency, and usability from the web interface.

The sensor module generated real-time and reliable readings of temperature, humidity, light intensity, wind speed, and rainfall detection. The sensor readings were uploaded to the cloud database, and displayed on the web dashboard, which was designed as a mobile compatible web application. The web dashboard provided easy access to information about the weather, not only from a laptop or desktop computer browser, but also from a smartphone browsing experience. The web dashboard had an auto-refresh function, and utilized AJAX updates to enable non-fresh instances of the web application to stay synchronized with the sensor and cloud updates. This provided real time responsiveness in the interface, and this level of responsiveness made the system highly practical for everyday life.

The AI-assisted prediction module effectively combined local sensor data with external meteorological information obtained from the Open-Meteo API. The hybrid rule-based model was able to forecast rainfall within a 15–30 minute window, based on conditions such as elevated humidity, low light, high cloud cover, and increased wind speed. For example, in one trial, when the humidity rose above 80% and cloud cover from the API exceeded 95%, the model correctly predicted an impending rainfall, triggering the motor to retract the clothesline before rain actually started. Sample outputs from the prediction API included JSON responses such as:

```
{
  "prediction": "🌧 Rain Likely in 15–30 mins",
  "score": 5,
  "sensor": {
    "temperature": "28",
    "humidity": "80",
    "light": "150",
    "wind": "12",
    "rain": "0"
  },
  "api": {
    "temperature": 24.8,
    "humidity": 78,
    "rain_mm": 0,
    "cloud_cover": 100,
    "wind": 17.9
  }
```

}

This result demonstrates how the system integrates real-time sensing with external forecasts to generate a proactive response rather than a purely reactive one. The prediction accuracy was generally quite acceptable for short-term predictions. However, further consideration could be given to the use of machine learning models rather than continuingly refining the rule-based model when improving the performance of the system is the priority in future research.

The actuation mechanism using a servomotor was robust and responsive, as demonstrated when activated by a rainfall detection and/or rainfall prediction. Once the NodeMCU detected rain or predicted rain, it operated as anticipated, and sent control signals to the servo to rotate the clothesline rod and move the clothing back under the covered location. The response time approximated less than 1.0 seconds from activation of either the detection or prediction trigger, which was timely to prevent serious wetting of clothing. The motor's movement was also recorded in the cloud database, enabling further transparency of the systems' actions to users monitoring the system using the dashboard.

The power subsystems consisted of a small solar panel, charge controller, and rechargeable battery pack and provided ample power to enable uninterrupted operation of the system irrespective of grid electricity. The solar unit was able to power the NodeMCU and sensors and servomotor over the period of daylight, plus reserve enough energy to operate at night. This demonstrates that the design is both eco-friendly and cost effective, or useful, for rural households and/or households susceptible to prolonged grid power failures.

VII. ADVANTAGES

The proposed weather-aware clothes drying mechanism offers several advantages over traditional methods and earlier automated systems

1. Proactive Rain Protection-
   Unlike conventional rain sensor-based systems that react only after rainfall begins, the integration of AI-assisted prediction allows the proposed system to anticipate rainfall 15–30 minutes in advance. This proactive approach ensures clothes are moved under shelter before they become wet.
2. Comprehensive Weather Monitoring-
   The use of multiple sensors, including temperature, humidity, light, rain, and wind sensors, provides a more holistic understanding of local environmental conditions. When combined with external weather API data, the system achieves higher reliability than single-parameter solutions.
3. Remote Accessibility via Cloud Dashboard-
   The PHP-based web dashboard, which is mobile-friendly and supports real-time updates, allows users to monitor weather conditions and system actions from anywhere. This remote accessibility increases convenience and aligns with modern smart home trends.
4. Sustainability Through Solar Power-
   The integration of a solar panel, charge controller, and rechargeable battery enables off-grid operation. This renewable power source reduces energy costs, ensures uninterrupted functioning during power outages, and makes the system eco-friendly.
5. Low-Cost and User-Friendly Design-
   The system uses affordable components such as NodeMCU, standard sensors, and a small solar unit, making it cost-effective and accessible for household adoption. Additionally, the straightforward circuit design and dashboard interface ensure ease of installation and use.
6. Real-Time Automation with Minimal Human Effort-
   Once installed, the system requires no manual intervention for operation. Clothes are automatically protected during rainfall events, reducing the need for users to constantly monitor changing weather conditions.
7. Scalability and Future Enhancement-
   The design is flexible and can be expanded with additional sensors or upgraded AI models. Historical sensor and weather data can be used to train machine learning algorithms in the future, further improving prediction accuracy.

VIII. LIMITATIONS & FUTURE WORK

8.1 Limitations:

1. Simplified **Prediction Model**
   The rain forecasting mechanism currently relies on heuristic decision rules applied to combined sensor and API data. While effective in short-term trials, this approach may not generalize well across different climates or sudden micro-climatic variations.
2. **Dependence on External Weather API**
   The accuracy of rain prediction is partly dependent on the availability and reliability of the external weather API. Network downtime or limited coverage of local weather conditions may affect system performance.
3. **Limited Actuation Capacity**
   The servo motor mechanism is suitable for small to medium household clotheslines. However, it may not scale effectively for larger setups, heavy loads, or industrial drying applications without stronger actuators.
4. **Energy Constraints during Extended Cloudy Periods**
   Although powered by solar energy, prolonged cloudy or rainy conditions may reduce battery charging efficiency, potentially limiting system operation if no backup grid supply is available.
5. **No Machine Learning Integration Yet**
   While the system collects valuable sensor and weather data, the current implementation does not utilize advanced machine learning algorithms, which could further improve predictive accuracy and adaptability.

8.2 Future Work:

To overcome these limitations and enhance system functionality, several directions for future development are proposed:

1. **Machine Learning-Based Prediction**
   Historical sensor and weather data can be used to train models such as logistic regression, decision trees, or neural networks for more accurate and adaptive rain forecasting.
2. **Edge Computing for Faster Decisions**
   Instead of fully relying on cloud processing, lightweight AI models can be deployed directly on the NodeMCU or an upgraded microcontroller (e.g., ESP32) to reduce latency and dependency on network connectivity.
3. **Enhanced Power Management**
   Hybrid power solutions combining solar with optional grid or wind energy could ensure uninterrupted operation during prolonged cloudy weather conditions.
4. **Scalable Mechanical Design**
   Stronger actuators, such as stepper motors or geared motors, may be introduced for larger clotheslines or community drying spaces, extending the system beyond household applications.
5. **Integration with Mobile Notifications**
   Future versions of the system could send SMS, push notifications, or voice alerts to users' mobile devices whenever rainfall is predicted or detected, increasing user engagement.
6. **Long-Term Field Testing**
   Extended trials across different geographic regions and climates will help refine prediction models, validate energy efficiency, and ensure robust performance under diverse environmental conditions.

IX. CONCLUSION

This work demonstrated the design and implementation of a smart, weather-aware drying mechanism that uses IoT, AI prediction, and solar energy combined into a single system. The system demonstrated the capacity to monitor environmental conditions with multiple sensors, transfer data to a cloud server, and display near real-time visibility through a mobile friendly web dashboard. The rule-based AI model incorporated sensor data into external weather data to allow the ability to predict rainfall with a 15–30 minute window, allowing the clothes to be retracted prior to rain falling.

The servo-motor based actuation mechanism, allowed the garments to be retracted automatically under shelter in response to rain detection and rain predictive capabilities. The renewable energy subsystem, loaded with a small solar panel and rechargeable battery validated the ability of the system to operate in a sustainable system independent of electricity. These features combined to make the proposed a cost-effective, eco-friendly, and practical solution for residential homes, especially where unpredictable weather and unreliable electricity may be a factor.

The design offers some novel benefits over contemporary clothesline automation systems, including prediction, incorporation with cloud, real-time remote monitoring, and energy independence. Advanced models based on machine learning, hybrid energy combinations, and better mechanical designs can resolve the design's limitations of being rule-based, being dependent on weather APIs, and lack of scalability with bigger drying systems.

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