

# Weather-Aware Adaptive Outdoor Protection and Comfort System Using Predictive IoT Automation

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**Abstract**—Any activity that occurs outdoors and is heavily dependent on the weather outside can be altered by natural climate shifts. Hanging clothes to dry outside is one activity that people still tend to do because it does not require any power from electricity, using sunlight and natural breeze instead. One disadvantage to this process is that it's fairly unreliable. If it rains unexpectedly, clothes hung outside will become damp quickly because they aren't brought inside soon enough. Plus, most people must keep an eye on outdoor drying spaces. So that they can try to avoid damage from sudden weather changes. Because of this, many people try to find automatic ways to dry their clothes. So they can adjust to weather changes without having to watch them. For this reason, in this paper we introduce a Weather Aware Adaptive Outdoor Protection and Comfort System implemented with IoT technology. The system combines instant rain detection with weather forecast data acquired from a web-based weather API. The data from the sensor is gathered and processed by an ESP8266 microcontroller controlling two servos driven hoods. The main hood keeps clothes dry by automatically deploying when the sensor module senses rain. There is also a secondary hood that can be used as an adjustable sunshade, providing full or partial shelter depending on the weather conditions or desired coverage. In addition to automatic activation, users can view conditions and take manual control of the hoods through a web based interface as well. It will allow us to react quicker and more reliable response to changing conditions by fusing instantaneous sensing and future-looking weather data. Continuous human oversight will also be reduced. We can also witness IoT based automation aiding smart decision making when it comes to outdoors, especially in smart homes of the future.

**Index Terms**—Internet of Things, Smart Automation, Weather Prediction, Adaptive Outdoor System, Environmental Monitoring, ESP8266

## I. INTRODUCTION

IoT-based connected devices with embedded sensors, controllers, and wireless communication facilitate the creation of smart automation solutions with faster response rates and very little human intervention. IoT solutions allow environmental monitoring and actuation of physical devices. Smart homes make use of IoT for improving efficiency and security of tasks done at home. Smart Lighting, environment monitoring and Automated Home Security are some examples of IoT Applications at Home.

One common task that automation can be applied to is outdoor drying tasks that are dependent on weather. Activities performed outdoors are often affected by environmental factors

such as temperature, humidity, and rainfall. Among these activities, outdoor clothes drying remains a widely used and energy-efficient method because it utilizes natural sunlight and air circulation instead of electrical appliances. However, sudden weather changes, particularly unexpected rainfall, can interrupt the drying process and cause inconvenience if clothes are not protected in time. As a result, users often need to continuously monitor outdoor drying areas to avoid potential damage caused by rain.

To address these challenges, several automated drying systems have been proposed in recent years. Many of these systems rely on environmental sensors such as rain detectors, light sensors, or humidity sensors to detect surrounding weather conditions and automatically adjust the drying structures. While these approaches reduce the need for constant manual supervision, most of them operate in a reactive manner. In such systems, protective actions are triggered only after environmental changes have already occurred, such as when rainfall has already begun.

Recent progress in cloud-based weather services has created new opportunities for improving the intelligence of automated systems. Modern weather platforms provide real-time environmental forecasts through application programming interfaces (APIs), delivering information about rainfall probability, temperature, humidity, and other atmospheric parameters. Overlaying predictive weather data on top of sensor-driven automation allows for smarter decision making and the ability to act before conditions occur.

Inspired by this idea, we present Weather Aware Adaptive Outdoor Protection and Comfort System using Predictive IoT Automation. Weather aware adaptive outdoor protection system combines real-time environment sensing along with online weather forecasting service API to create a solution for outdoor drying space management system. The rain detector sensor is used to sense real-time environmental conditions while the weather forecast API gets online weather forecast information to be processed by ESP8266 based microcontroller and actuate dual servo driven hoods ensuring user protection as well as comfort.

Whenever there is a rainfall, first hood closes automatically to keep clothes away from wetness. The second hood acts as a canopy hood which provides shade or semi-cover depending

on your weather forecast or the preference of the users. We have also introduced a dashboard user-interface that allows you to check the weather and control the hoods manually if needed.

Highlights of this project:

- Proposed IoT Based Adaptive Outdoor Protection System with using ESP8266 microcontroller.
- Rain Detection with real-time weather forecast from cloud based system.
- Automated Clothes Hood and Outdoor Hood using dual servo mechanism.
- Developed Dashboard system for Remote Monitoring and Control.
- Extensible Model for Smart Home Application.

The rest of this paper is divided into sections as follows. Section II discusses prior work and current solutions for automated drying technologies. Section III gives details for system design and architecture. Section IV shows the hardware prototype implementation of the system. Section V will give testing results and system analysis. The paper concludes with the discussion of future work and improvements.

## II. LITERATURE REVIEW

Emerging Internet of Things (IoT) technologies have had substantial impact on automated monitoring and control systems development. Sensor networks, embedded microcontrollers, and wireless communication technologies, forming an IoT system, enable gathering data about surroundings and acting upon collected information. Efficiency of automated systems improvement and environment monitoring were proven to be useful applications of IoT platforms in number of works [1], [2].

Smart homes are amongst the most studied implementations of IoT automation systems. Existing smart home frameworks utilize connected sensors and messaging ports to monitor indoor climates as well as remotely regulate home appliances. Studies have emphasized the relevance of secure and efficient IoT system implementation towards enhanced convenience, security, and energy efficiency in smart homes [3], [4].

Smart home automation architectures have also been suggested by other studies. These systems sensed environmental factors and allowed remote controlling of appliances in order to maintain systems throughout the home. [5], [6].

Monitoring environments through IoT based sensors networks have been another popular topic of study. Sensors allow for monitoring of environmental factors such as temperature, humidity, rain fall, and atmospheric pressure. These sensor based systems allow for real time monitoring of these environmental aspects. These types of systems are commonly used for applications such as environment management and smart structures [7], [8]. Recent research has investigated how high-level IoT nodes can preprocess environmental data locally and then send the information to cloud services for further analysis [9].

Applications of IoT technology include city-scale infrastructure and smart city projects. Proposed smart monitoring

systems can provide automatic environment sensing and resource management in cities [10]. Furthermore, newer smart building architectures have been designed to leverage IoT communication protocols to help with monitoring efficiency and intelligent building automation. [11]. Analytical methods have been employed to data collected from IoT monitoring to help aid decision making and enhance system performance. [12].

Energy efficiency is yet another area where IoT-based automation solutions shine. IoT-enabled energy management systems were recently suggested in research that looks at monitoring energy usage while controlling connected device operations automatically for optimal efficiency and sustainability. [13]. These are the demonstrations of how networked sensors can help bring smart-home technology to the management of commercial buildings and living spaces.environments.

While a number of IoT based home automation and building management systems have been proposed for smart buildings and environments, not much research has been done in the area of dynamic sheltering systems which intelligently merge environmental sensor readings with forecast weather data. The majority of current prototypes are based on trigger-based systems that react once conditions have already been met.

The above drawbacks can be tackled by enabling real-time rain detection along with weather forecast data fetched from online APIs. Microcontroller based on ESP8266 sense environmental data and uses it to operate two servo motors attached to hoods that can shield the clothes from rain, whilst keeping the outdoors comfortable. Fusing weather forecast data with online automation helps pave the way for smarter outdoor automations.

## III. PROPOSED SYSTEM

Weather-Aware Adaptive Outdoor Protection and Comfort System aims at automating outdoor clothes drying areas using environment sensing, weather forecasting and automated structural actuation. The objective of this system is to require minimal supervision yet effectively protect outdoor drying areas from unexpected weather.

The ESP8266 NodeMCU microcontroller serves as the brain behind the operation as it is the core of the system. It accepts input from sensors that read the environment, handles retrieved weather data from online APIs, and manages the system actuators and the other components. Additionally, the ESP8266 has built-in Wi-Fi capabilities allowing for integration with a web dashboard for online monitoring and for manual operation.

Rain detection sensor which is integrated with the system is used to sense live environmental parameters. So when it detects rain, it sends a signal to ESP8266 controller. Then the ESP8266 will make hood covers down by servo motor which is activated with the sensor readings. This protects the clothes from rain and its exposure to it. So that whenever it rains, it will immediately react so that clothes won't get wet while drying outside.

In addition to sensing in real-time, the system is also implemented with a forecast weather detection. We can pull

TABLE I  
COMPARISON OF EXISTING IOT-BASED AUTOMATION SYSTEMS

Reference	System Type	Sensors Used	Weather Prediction	Automation Mechanism	User Interface
[1]	IoT monitoring system	Environmental sensors	No	Data monitoring	Basic interface
[2]	Environmental monitoring	Multiple sensors	No	Automated alerts	Dashboard
[3]	Smart home automation	Smart home sensors	No	Device automation	Mobile interface
[5]	Smart home control system	IoT sensors	No	Home automation	Web interface
[6]	Energy management system	Energy sensors	No	Energy control	Monitoring dashboard
[7]	Smart city monitoring	Environmental sensors	No	Monitoring system	Cloud interface
[8]	Environmental monitoring	Sensor networks	No	Monitoring framework	Remote access
[9]	IoT environmental node	Multi-sensor module	No	Data collection	Monitoring system
[12]	Smart building monitoring	Building sensors	No	Data analysis	Visualization interface
[11]	Smart building automation	IoT devices	No	Building automation	Smart control system
[10]	Smart city automation	Sensor networks	No	Infrastructure monitoring	IoT platform
[13]	Energy management system	IoT sensors	No	Energy optimization	Control dashboard
[4]	Smart home security	Security sensors	No	Security automation	Mobile interface
[14]	Smart environment monitoring	Environmental sensors	No	Monitoring system	IoT dashboard
<b>Proposed System</b>	Weather-aware outdoor protection	Rain sensor	Yes	Dual servo hood mechanism	Web-based dashboard

information from online weather services using an API. Online weather services like OpenWeatherMap can tell the chance of rain, temperature, and humidity. The system use this forecast data to predict potential weather and position our outdoor fixture as needed.

The total design includes for two servos to control the hood. The primary hood would close upon sensing rain to shield clothes left out to dry which ensures the clothes in the outdoor is safe. The second hood is like an awning for shade or part shade and it ensures the comfortability based on the preference of the user.

In addition to automated operation, a web-based dashboard interface is implemented to provide system monitoring and manual control capabilities. Through this interface, users can observe environmental information and remotely activate or deactivate the hood mechanisms when necessary. This functionality improves system flexibility and allows users to interact with the system conveniently.

Along with being automatic there is also a web dashboard implemented for providing information about the system currently and to control manually. This allows the user to monitor the system and manually turn the hoods off or on if needed. With this one can see environmental data and turn the hoods off and on remotely conveniently.

With some clever usage of environmental sensing capability along with predicted weather information and actuation automation, the system devise an automated solution for keeping tabs on and intelligently operating outdoor drying racks. This IoT-based solution allows for both monitoring and automated action based on changes in weather.

### A. System Architecture

The system can be divided into sensing components, micro-controller based processing system, cloud messaging services and user interface components. ESP8266 NodeMCU acts as the controller which triggers sensing, analyzes the sensed information and operating mechanical components of the system based on the sensed environment.

For monitoring the environmental conditions a rain detector is used. The rain sensor operates by sensing the water droplets

on its sensing element, and provides a digital output when it rains. The sensor output signal is fed to ESP8266. The controller interprets the signal given by the sensor and decides which control needs to be given. On detecting rains, it turns ON the servo motor which controls the hood.

In addition to real-time environmental data sensing, weather forecast information is also acquired from online weather services by the usage of a weather API. Weather forecast information such as rainfall probability and any other parameters are retrieved over the ESP8266's internet connection. Predictive data allows for the system to more accurately predict possible weather developments.

Servo Motors are used as Actuators in this system. The ESP8266 will transmit signals to servo motors which will move the hood with its adjustable mechanism. With sensing, communicating and finally actuating, our system is capable of automating tasks along with remote observation over IoT dashboard.

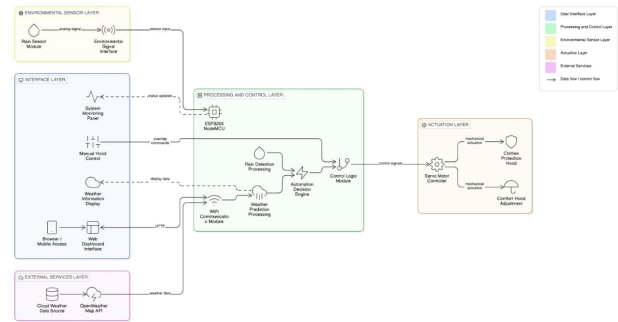


Fig. 1. System architecture of the proposed weather-aware IoT system

### B. Operational Workflow

Working operation of this system are as follows. Monitor the environment constantly with a rain sensor. The rain sensor will sense if there is any moisture or rain in the environment.

When droplets of water are present on the rain sensor, it will send a signal to the ESP8266 controller.

On receiving this signal, micro-controller reads the input, amplifies and decides the output accordingly. On a positive signal indicating rain, micro-controller will command the servo motor to close the hood structure automatically. By doing so the clothes kept out for drying will remain unaffected by rain.

Simultaneously, the system transmits its operational status to the web-enabled dashboard. The dashboard allows the user to view system activity and the surrounding environmental conditions. Alerts and device status keep users informed about how the system is operating when they are away from the drying site.

### C. Control Mechanism

This system will have two modes of operation. Automatic and Manual control. Automatic mode means that the system will run on its own independently responding to the environment around it using the rain sensor. The ESP8266 will constantly read the rain sensor and open or close the servo-operated hood when rain is detected.

Apart from automatic mode, the system has a provision for manual mode also. The hood motors can be controlled manually using the IoT dashboard as per the user's requirement. Hood can be opened or closed by using dashboard irrespective of sensor values.

Having both automatic and manual modes allows for a more versatile and dependable system. We can rely using the automation for unpredicted weather anomalies yet still have the ability to control things manually when necessary to give an balance between the system.

## IV. HARDWARE ARCHITECTURE

The hardware subsystem of the proposed system includes sensing elements, microcontroller-based processing unit, actuation elements and communication modules. Overall hardware components work in conjunction to sense ambient conditions and automatically or manually trigger protection whenever needed.

The main brain behind the entire system is the ESP8266 NodeMCU microcontroller which handles processing and communication. A rain detection sensor is used for monitoring the weather and servo motors are used to operate the hoods covering the clothes from rain and providing adjustable coverage from outdoors.

### A. ESP8266 NodeMCU

The ESP8266 NodeMCU is an IoT development board based on popular Wi-Fi enabled microcontroller. The ESP8266 NodeMCU is used as the main controller for our proposed system. It will handle reading sensors, running control algorithms and interfacing with outside services.

The ESP8266 comes with built in Wi-Fi, with the operation of this, the system can access internet enabled things such as weather API's and IOT dashboard services. Once connected to

the network it can download weather forecast, enable remote monitoring of the system as well as allow users to interact with the system with the help of dashboard. Microcontroller provides control signals to the servo motors which in turn controls the hoods.

### B. Rain Detection Sensor

The rain sensor is a rain detecting module that detects rainfall in the environment. This sensor includes a sensing plate and a comparator circuit which outputs digital signal when moisture or water droplets comes in contact with sensing plate.

Whenever raindrops hit on sensing plate, the electrical conductance on the sensing plate varies which makes the sensor module send a signal to ESP8266 microcontroller. Here ESP8266 microcontroller analyses the given input and gives instructions to the protective hood mechanism using the two servo motors. The entire process allows instantaneous detection whenever it rains.

### C. Servo Motor Mechanism

Servo motors provide actuation that positions the hood assemblies. The two servo driven systems one for shade sail and one for protection against rain performing different tasks.

The servo motor one controls the protective hood which closes when rain is sensed automatically. This prevents clothes hanging to dry outside from getting wet. The servo motor two adjusts a shade sail with adjustable mechanism, allowing full or partial awning coverage as per the requirements of the user.

Servo motors are selected for this uses because they offer precise positioning of hoods, stable operation, and easy integration with microcontroller-based control systems.

### D. Power Supply and Connectivity

Power is supplied to the whole system through USB based power supply which is connected to the ESP8266 NodeMCU module. The power supply provides adequate operating voltage to drive the micro-controller along with the attached peripheral devices.

ESP8266 provides Wi-Fi connection between the hardware system and the user interface. This helps the system send and receive data from the IoT dashboard and outside weather services. So that we can monitor and control the system from anywhere and get weather forecast.

## V. SOFTWARE IMPLEMENTATION

The software framework of the proposed system combines embedded microcontroller programming, IoT communication protocols, and cloud-based services to enable automated monitoring and control of the outdoor protection mechanism. The ESP8266 NodeMCU microcontroller executes the control algorithms while maintaining wireless communication with external platforms.

The software environment of the proposed system architecture involves programming the embedded microcontroller with IoT and cloud capabilities to allow for automatic monitoring

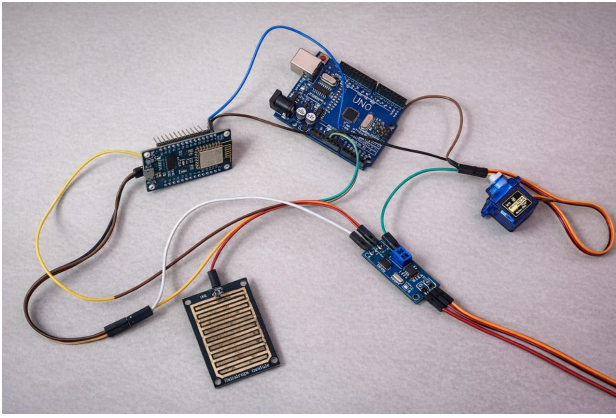


Fig. 2. Prototype implementation of the proposed system

and manipulation of the outdoor protector device. Running the control sequences on the ESP8266 NodeMCU microcontroller, this system can wirelessly communicate with outside networks or cloud.

#### A. IoT Dashboard Integration

The Blynk IoT platform is interfaced to allow the system to be controlled remotely from the cloud server. The ESP8266 connects to the Blynk cloud server wirelessly through its Wi-Fi functionality. The information is relayed between our system and the Blynk app.

By using the app dashboard, you will be able to view the status of the system and be notified when it rains so you can operate the hood manually.. The platform also supports notification services that inform users whenever rainfall is detected and the protective hood is automatically activated.

#### B. Embedded System Programming

The control logic of the system is developed using the Arduino Integrated Development Environment (IDE). The ESP8266 microcontroller is programmed to continuously read input signals from the rain detection sensor and execute corresponding control actions depending on the detected environmental conditions.

When rainfall is detected by the sensor module, the ESP8266 interprets the input signal and sends control commands to the servo motor responsible for operating the protective hood structure. This action ensures that the hood closes automatically to prevent clothes from being exposed to rainwater.

The embedded software also implements conditional control logic that supports both automatic and manual operating modes. In automatic mode, the microcontroller independently monitors sensor readings and activates the hood mechanism when rainfall occurs. In contrast, manual mode allows users to directly control the hood mechanisms through the IoT dashboard interface.

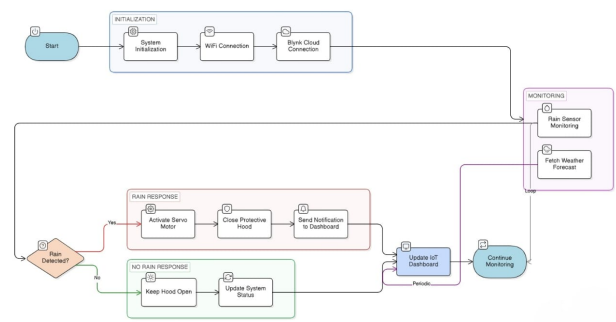


Fig. 3. Software Workflow for the Proposed System

## VI. SYSTEM IMPLEMENTATION AND CONTROL

### A. Weather API Integration

Other than just reacting to the current environment detected by its sensors, the system also utilises forecast data from a third party weather service to predict weather conditions. Forecast data from OpenWeatherMap API included chance of rain and temperature.

The ESP8266 will make HTTP requests to the weather service via Wi-Fi at regular intervals. Forecast information is parsed by the microcontroller to identify whether it might rain. If rain is forecast, users are made aware of the upcoming environmental conditions so that they can prepare the outside drying space.

### B. Control Algorithm

The operation of the system is that the microcontroller runs a control algorithm programmed into its ESP8266 firmware. The algorithm reads inputs from sensors and checks or evaluates for the mode of operation of the system.

If rain sensor detects water, the controller sends a signal to rotate the servo and close the hood. If there is no rain, the hood will remain open to provide maximum sunlight and air circulation for faster drying.

Commands sent from IoT dashboard will allow one to operate each hood override normal operation. The control logic provides smooth operation of sensor reading, cloud data transfer, and servo operations.

## VII. EXPERIMENTAL RESULTS AND PERFORMANCE EVALUATION

A prototype of the weather aware outdoor protector was assembled to evaluate the efficiency and effectiveness of the system it in different weather conditions. The components used were ESP8266 NodeMCU microcontroller unit, rain sensor module, servo motors as actuators and cloud connected IoT Dashboard.

The prototype was tested in order to confirm its working of detecting rain, automatically controlling hood mechanism and real-time monitoring capabilities through the IoT dashboard. Different scenarios were applied to observe system behavior in automatic and in manual operating modes.



affordable and practical solution to better manage outdoor spaces.

## IX. FUTURE SCOPE

The system can also include other environment sensors like temperature and humidity sensors for handling the automations more effectively. This will allow the system to sense more information about its environment and have better awareness about the weather.

Future implementations of the system could allow for machine learning techniques to allow for predictive decisions as well. By pulling from previous weather and environmental data, more relevant predictions may be drawn to improve its efficiency.

As far as hardware designs are concerned, the hood housing can be modified to accommodate greater drying surface areas as well as provide greater mechanical rigidity. Improvements to mechanical design will allow for more realistic application inside the home.

Another improvement could be allowing this system to integrate with larger smart home systems. If the system could connect to other smart home devices with IoT capabilities we could develop smart homes that allow for smart management of your indoor environment.

## X. CONCLUSION

This article describes a weather-aware automated outdoor protection and comfort system developed for automated control of clothes drying outdoors. It incorporates rain sensor, servo-driven hood-lifting mechanism and ESP8266 NodeMCU based microcontroller for protection and comfortability.

Traditional outdoor drying machines typically demand a significant amount of manual surveillance. Their inability to quickly adapt to changing conditions automatically, such as rainstorms or unexpected weather, often causes inconvenience to users or ruins clothing. These issues highlight the necessity for smarter systems that can work independently and responsively to the environment.

The architecture suggested uses realtime environmental sensing along with predictive sensing through a weather API. The architecture also includes remote sensing and manual override through an IoT dashboard that includes manual control.

The experimental results proved that our prototype system can recognize rain and automatically operate the hood to shield clothes from raindrops. There is also an extra provision for manual control using the dashboard which allows users to control the system both for the protective hood and for the comfort hood.

In conclusion, this system serves as a demonstration of how IoT technologies can help us build smart outdoor automations. Using sensing, communication, and automated controls together we were able to build a system to help increase convenience outdoors.

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