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Design and Development of an IoT-Based Automatic Drying Cabinet Using ESP32 for Clothes, Shoes, and Helmets

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Abstract*—The dependence of conventional drying methods on unpredictable weather conditions often hinders the drying efficiency of clothes, shoes, and helmets. This study therefore aims to develop and test an Internet of Things (IoT)-based Automatic Drying Cabinet using ESP32 for clothes, shoes, and helmets that is able to monitor the temperature and humidity of the objects in real time through the Telegram application. The research method used is Research and Development (R&D) with a V-Model development approach covering requirement analysis, system design, architecture design, module design, software implementation, unit testing, integration testing, system testing, and acceptance testing. The developed system uses an ESP32 microcontroller integrated with a DS18B20 module, three Capacitive Soil Moisture modules to detect the moisture level of the objects, relays to control the heating and fan systems, and an I2C LCD as a local display. Sensor reading data is transmitted over the internet and displayed in real time on a Telegram Bot. The system can also receive user commands to activate and deactivate the drying process through Telegram and automatically controls the heater based on a predetermined temperature value. Test results show that the DS18B20 module, over a measurement range of 32.0°C–52.7°C, achieved an average accuracy of 99.38% compared with a TP-101 digital thermometer, while the Capacitive Soil Moisture module, over a humidity range of 10%–86%, achieved an average accuracy of 98.6% compared with an MT-10 measuring instrument. Functional testing of the heating system, fan system, and Telegram integration showed a 100% success rate, and overall system testing showed that the drying process for clothes, shoes, and helmets proceeded according to the predetermined conditions.

***Index Terms*—*ESP32, Internet of Things, Automatic Drying Cabinet, Telegram Bot.*

I. INTRODUCTION

In daily life, clothes, shoes, and helmets are essential items that support people's activities. However, the drying process for these three types of items is often hampered by unpredictable weather and high air humidity. High humidity has been shown to slow down the drying process of textile materials and increase the risk of microorganism growth on clothing fibers [1]. As a result, clothes, shoes, and helmets require a longer time to dry, which can potentially cause unpleasant odors, mold, and bacteria that may affect health.

Based on an analysis of Indonesia's rainfall in October 2025, most regions experienced medium to high rainfall, so that drying processes relying on sunlight became less than optimal, particularly during the rainy season [2]. This condition indicates that conventional drying methods have not been able to guarantee a fast and stable drying process. In addition to depending on the weather, this method also lacks a temperature control or automatic humidity monitoring mechanism, making it difficult to maintain drying quality [2].

Various dryer products available on the market are generally designed for a single function, such as drying clothes or helmets only, and are therefore unable to accommodate different types of items within a single system. Furthermore, most devices are not yet equipped with automatic, real-time monitoring of drying conditions. The development of the Internet of Things (IoT) enables the integration of sensors with control systems to continuously monitor and regulate the drying process [3]. The ESP32 microcontroller supports Wi-Fi connectivity, sensor data processing, and actuator control, making it suitable for use as the central controller of a smart drying device [4]. Therefore, this study proposes the development of an IoT-based automatic drying device using ESP32 that is able to precisely control temperature and humidity and monitor drying conditions in real time, so that the drying process becomes more effective, efficient, and safe.

II. LITERATURE REVIEW

A. Clothing

Clothing is a textile material with physical characteristics such as fiber structure, weave pattern, and material density that affect its mechanical properties, comfort, and quality of use [5]. The composition of the constituent fibers, whether derived from natural or synthetic sources, determines the fabric's ability to absorb moisture, its tensile strength, flexibility, and surface air circulation. Variations in fiber composition, fabric construction technique, and textile finishing produce different types of clothing with distinct functions and characteristics, making an understanding of the basic structure of clothing an important part of textile and material engineering studies.

B. Shoes

A shoe is a footwear product consisting of an upper and a sole designed to protect and support the user's foot while adapting to the activity and environmental conditions [6]. Shoes play an important role in user comfort and safety; when the sole or upper material becomes damp or damaged, the friction-absorption,

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stability, and foot-ventilation functions are disrupted, which can ultimately lead to ineffective drying, microorganism growth, odor, and reduced service life.

C. Helmet

A helmet is a head-protection device that must be used by motor-vehicle riders to ensure safety and compliance with traffic regulations [7]. A helmet is designed not only to cover the head but also to absorb impact, protect against flying objects, and keep the head in position to avoid injury during an accident, so that selecting a helmet that meets standards and using it correctly are important factors in determining its effectiveness.

D. ESP32 Microcontroller

ESP32 is a chip manufactured using 40 nm technology that integrates 2.4 GHz Wi-Fi and Bluetooth, designed to deliver strong power and radio performance while maintaining resilience and reliability across various application scenarios [14]. The dual-mode feature of the ESP32 module is utilized to simplify the development of Internet of Things (IoT)-based systems, so that the transmission of temperature and humidity data from the drying cabinet can proceed stably and efficiently.

E. DS18B20 Temperature Sensor

The DS18B20 module is a digital temperature sensor capable of measuring over a wide range, from –50°C to 125°C [8]. It operates at 5 V with a very low current consumption of less than 5 mA, making it power-efficient and flexible for use in electronic applications that require minimal energy consumption.

F. Capacitive Soil Moisture Sensor

The Capacitive Soil Moisture module is an electronic device used to measure water content by utilizing changes in the capacitance value of its electrodes [10]. The electrode acts as a capacitor with a certain reactance relative to the input signal; an increase in water content raises the capacitance value, which is inversely proportional to the reactance, resulting in a decrease of the signal-line voltage. This change in analog voltage is then read by a microcontroller pin as a real-time representation of the moisture level of the object.

G. Heating System

The heating system consists of a relay module and a heater. A relay is an electromechanical component that functions as an automatic switch, in which a coil is energized with DC current to open or close Normally Open (NO) and Normally Closed (NC) contacts, allowing a low-current signal to control a high-voltage load [14]. This component is vital in the architecture of the automatic drying cabinet because the ESP32 microcontroller cannot directly deliver the large power required by the heating element; the relay therefore serves as both an isolator and a switch that regulates the on–off cycle of the heater based on logical instructions from the control system. A heater converts electrical energy into heat through a resistive element, allowing it to controllably raise the air temperature inside a space [9]. The heater accelerates the drying process because hot air increases the rate of water evaporation from the material; it may take the form of a conventional heating element or a Positive Temperature Coefficient (PTC) heater.

H. Fan System

The fan system consists of a relay module and a DC fan. A DC fan is an electromechanical device that uses a copper-wire coil to generate an electromagnetic field when current flows through it [11]. Rotation occurs when direct current flows into the motor circuit, where the coil creates a magnetic field that interacts with a permanent magnet, producing a continuous rotational force on the blades as long as current flows.

I. I2C LCD Module

The I2C LCD module is a character display that utilizes a two-wire communication protocol, SDA and SCL, which simplifies data transmission compared with a parallel interface that requires more communication lines [12]. The I2C interface allows for microcontroller pin savings because a PCF8574-based adapter converts the LCD's parallel signal into a serial signal, so that the module only requires four main connections: VCC, GND, SDA, and SCL. This characteristic makes the I2C LCD more efficient for device integration, particularly in automatic systems with many sensors or actuators.

III. RESEARCH METHOD

A. Research Design

This study employs the Research and Development (R&D) method with a V-Model development approach. The V-Model is a development of the waterfall model but has a branching structure that emphasizes the close relationship between the system development process and its corresponding testing stage. The V-Model covers several main stages: Requirement Analysis & Acceptance Testing, System Design & System Testing, Architecture Design & Integration Testing, and Module Design & Unit Testing, ending with the Coding phase [13], as shown in Fig. 1.

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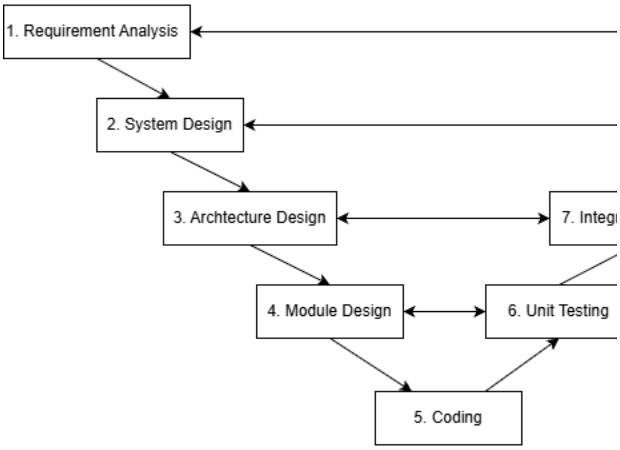

Fig. 1. Stages of the V-Model research design used.

The research and device testing were carried out at the Control Instrumentation Laboratory, Electrical Engineering Education Study Program, Faculty of Engineering, Universitas Negeri Jakarta. The equipment used in testing included a drying cabinet equipped with a heating system (heater), a fan system (DC fan), a DS18B20 module (temperature sensor), and a Capacitive Soil Moisture module (humidity sensor), together with supporting modules for the ESP32-based control system. The drying objects used in the tests consisted of an undergarment, a canvas shoe, and a helmet.

B. System Block Diagram

Fig. 2 shows the block diagram of the system.

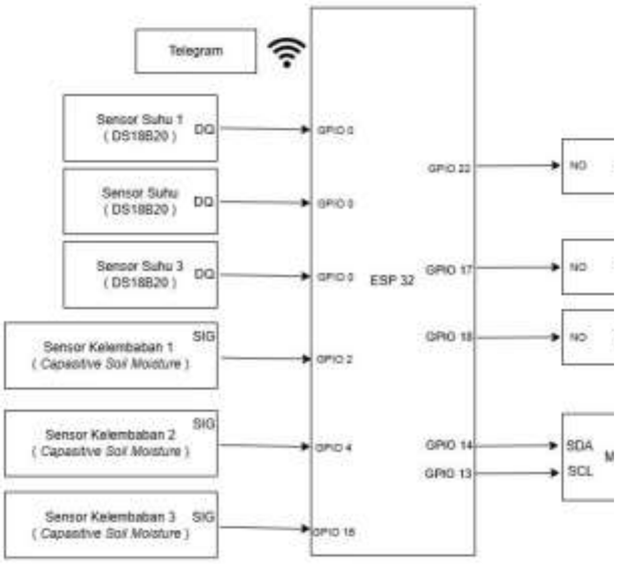

Fig. 2. System block diagram.

Based on Fig. 2, the system consists of several main parts with different functions. The DS18B20 temperature sensor measures the air temperature inside the drying chamber. Three separate Capacitive Soil Moisture sensor units are used to detect the moisture level of the clothes, shoes, and helmet directly. All sensor data are processed by the ESP32 before being sent to the Telegram platform over the internet for remote monitoring. The system is equipped with two actuators controlled through relay modules. The DC fan circulates hot air inside the drying chamber and operates continuously throughout the drying process, while the PTC heater automatically switches ON/OFF to keep the chamber temperature stable at the predetermined setpoint: when the chamber temperature is below the setpoint the heater activates, and when it reaches or exceeds the setpoint the heater turns off. The drying process is considered complete when all three Capacitive Soil Moisture sensors detect that the moisture levels of the clothes, shoes, and helmet are below the threshold; the ESP32 then automatically turns off both actuators and sends a completion notification to the user via Telegram.

C. Testing Procedure

During overall product testing, drying-cabinet performance data were collected in turn for each test object: undergarment, canvas shoe, and helmet. The user places one type of material inside the drying chamber, and after the object is positioned precisely, the tip of the Capacitive Soil Moisture plate is clipped onto the material. The cabinet door is then closed, and the ESP32 is powered on to trigger the heater relay while monitoring chamber-temperature stability through the DS18B20 module. When the Telegram notification indicates a dry status and the relay has automatically cut off current to the heater, the user removes the test object. The procedure is then repeated for the remaining objects, following the same operational sequence, until all items have been tested.

IV. Results and Discussion

A. DS18B20 Accuracy Test

Table I presents the accuracy test results of the DS18B20 module against the TP-101 digital thermometer over a temperature range of 32.0°C–52.7°C. The measurement error ranged from 0.19% to 1.25%, corresponding to an average accuracy of 99.38%.

TABLE I. DS18B20 Accuracy Test Against Reference Thermometer

No.	TP-101 (°C)	DS18B20 (°C)	Error (°C)	% Error	Accuracy
1	32.0	32.4	0.4	1.25%	98.75%
2	32.1	32.3	0.2	0.62%	99.38%
3	42.2	42.4	0.2	0.47%	99.53%
4	52.3	52.4	0.1	0.19%	99.81%
5	52.7	52.4	0.3	0.57%	99.43%

B. Capacitive Soil Moisture Accuracy Test

Table II presents the accuracy test results of the Capacitive Soil Moisture module against the MT-10 measuring instrument for the three test objects (undergarment, canvas shoe, and helmet) at wet, damp, and dry conditions, over a humidity range of 10%–86%. The module achieved an average accuracy of 98.6%.

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TABLE II. Capacitive Soil Moisture Accuracy Test Against Reference Instrument

Sensor & Object	Condition	ADC (ESP32)	Sensor %	MT-10 %	Error	Accuracy
Sensor 1 (Undergarment)	Wet	1475	86%	84%	2%	98%
	Damp	2061	45%	45.6 %	0.6%	99.4%
	Dry	2558	10%	9%	1%	99%
Sensor 2 (Canvas shoe)	Wet	1536	82%	80%	2%	98%
	Damp	1919	55%	53%	2%	98%
	Dry	2487	15%	14%	1%	99%
Sensor 3 (Helmet)	Wet	1507	84%	83%	1%	99%
	Damp	1891	57%	55%	2%	98%
	Dry	2487	15%	14%	1%	99%

C. Heating and Fan System Functional Test

Table III shows that the activation, deactivation, and 10-minute stability tests of the heating system all achieved a Success status. Table IV shows that the activation and deactivation tests of the fan system likewise achieved a Success status.

TABLE III. Heating System Functional Test

No.	Test Type	Success Parameter	Status
1	Activation (ON)	Relay clicks, indicator lamp lights, heater becomes hot	Success
2	Deactivation (OFF)	Indicator lamp turns off, heater temperature gradually decreases	Success
3	Stability (10 min)	Heater kept ON for 10 minutes with stable temperature and no disturbance	Success

TABLE IV. Fan System Functional Test

No.	Test Type	Success Parameter	Status
1	Activation (ON)	Relay clicks, indicator lamp lights, fan blades rotate	Success
2	Deactivation (OFF)	Indicator lamp turns off, fan blades stop rotating completely	Success

D. System Integration Test

Table V summarizes the integration test between the sensor modules, actuators, and the Telegram Bot. All five integration scenarios achieved a Success status.

TABLE V. System Integration Test

No.	Integration Scenario	Expected Result	Status
1	DS18B20 & Heater	Heater relay ON below setpoint; OFF above setpoint	Success
2	Soil Moisture & Fan	Fan ON when moisture > 15%; OFF when < 15%	Success
3	ESP32 & Telegram (notification)	Bot sends a real-time “drying complete” message	Success
4	ESP32 & Telegram (monitoring)	Bot replies with current temperature and humidity data	Success
5	System stability (no conflict)	No restart, Wi-Fi stays connected, stable sensor readings	Success

E. Drying Duration Test

Tables VI–VIII present the drying duration for each object at different initial wetness levels. The undergarment was dried at a target temperature of 55°C, while the canvas shoe and helmet were dried at 45°C.

TABLE VI. Drying Duration Test — Undergarment (55°C)

Initial Wetness	Water Content	Sensor Humidity	Duration
Damp	11%–50%	45%	26 min
Wet	51%–80%	70%	53 min
Very wet	81%–100%	92%	89 min

TABLE VII. Drying Duration Test — Canvas Shoe (45°C)

Initial Wetness	Water Content	Sensor Humidity	Duration
Damp	16%–50%	40%	17 min
Wet	51%–80%	65%	93 min
Very wet	81%–100%	88%	142 min

TABLE VIII. Drying Duration Test — Helmet (45°C)

Initial Wetness	Water Content	Sensor Humidity	Duration
Damp	16%–50%	35%	33 min
Wet	51%–80%	60%	74 min
Very wet	81%–100%	85%	131 min

F. Temperature Stability Test

Tables IX–XI show the temperature-stability test results for the undergarment, canvas shoe, and helmet, respectively. In each case, the measured temperature converged to the setpoint within a few minutes and remained stable while humidity decreased steadily until the drying process ended.

TABLE IX. Temperature Stability Test — Undergarment (Setpoint 55°C)

Time (min)	Setpoint	Measured Temp.	Humidity
0 (start)	55°C	28.5°C	33%
5	55°C	52.1°C	30%
10	55°C	55.8°C	29%
15	55°C	55.2°C	28%
20	55°C	54.9°C	27%
89 (end)	55°C	55.1°C	9%

TABLE X. Temperature Stability Test — Canvas Shoe (Setpoint 45°C)

Time (min)	Setpoint	Measured Temp.	Humidity
0 (start)	45°C	28.2°C	22%
2	45°C	36.5°C	20%
4	45°C	44.8°C	18%
6	45°C	45.1°C	16%
8	45°C	44.9°C	16%
10	45°C	45.2°C	15%
12 (end)	45°C	45.0°C	14%

TABLE XI. Temperature Stability Test — Helmet (Setpoint 45°C)

Time (min)	Setpoint	Measured Temp.	Humidity
0 (start)	45°C	28.0°C	26%
5	45°C	44.1°C	24%
7	45°C	45.2°C	22%
11	45°C	44.8°C	20%

Time (min)	Setpoint	Measured Temp.	Humidity
13	45°C	45.1°C	18%
15	45°C	44.8°C	16%
17 (end)	45°C	45.0°C	14%

G. Acceptance Test

Table XII summarizes the acceptance test conducted with a system user. All five usage scenarios, from starting the bot to receiving the completion notification, achieved a Success status.

TABLE XII. Acceptance Test Results

No.	Usage Scenario	Expected Bot Response	Status
1	Starting the bot	Bot replies in Auto mode and shows the menu (Check Status, Check Temperature, Auto Mode, Manual Mode)	Success
2	Selecting drying mode	Bot replies “Manual Mode Active” and shows the manual control menu (Heater ON/OFF, Fan 1 ON/OFF, Fan 2 ON/OFF, Check Status, Turn Off All, Back to Auto)	Success
3	Checking current status	Bot sends real-time temperature, humidity, and device status (ON/OFF)	Success
4	Receiving completion notification	Bot automatically sends “COMPLETE & STANDBY TOTAL”	Success

H. Discussion

The test results show that all system components, including the sensors, actuators, and IoT communication, worked according to the design. The DS18B20 and Capacitive Soil Moisture sensors exhibited high accuracy, while the heater, fan, and Telegram integration achieved 100% functional success. Furthermore, the system was able to effectively dry clothes, shoes, and helmets while keeping the temperature stable throughout the drying process. These results indicate that the developed automatic drying cabinet is able to operate reliably and meets the objectives of the study.

V. CONCLUSION

Based on the research that has been conducted, it can be concluded that this study successfully developed an Internet of Things (IoT)-based Automatic Drying Cabinet using ESP32 for clothes, shoes, and helmets using the V-Model development approach. The developed system successfully integrates a DS18B20 module, Capacitive Soil Moisture modules, a heating system, a fan system, and Telegram as the monitoring and remote-control media. Test results show that all system components function as designed: the DS18B20 module reads temperature well, while the Capacitive Soil Moisture module can detect the moisture level of clothes, shoes, and helmets. The heating system and fan system also operate stably in assisting the drying process inside the cabinet. Based on the drying-process test results, the system is able to reduce the moisture level of clothes, shoes, and helmets from a wet to a dry condition, with clothing moisture successfully reduced to 10% and shoe and helmet moisture reduced to 15% at the final drying condition. Compared with a commercially available dryer (the V-Fresh brand commonly found in basement areas), the developed cabinet has three key operational differences. First, in the stopping mechanism: the V-Fresh dryer relies on a static timer without detecting the material's condition, whereas the developed system automatically switches off the heater and fan once the sensors detect that the target dryness level has been reached. Second, in heat control: the V-Fresh dryer applies continuous heat exposure, whereas the developed cabinet cycles the heater relay on and off based on the chamber temperature limit to avoid the risk of overheating. Third, in remote-monitoring capability: the temperature and dryness status of the items can be monitored in real time through the Telegram application, a function not available on the V-Fresh dryer.

Based on the results of this study, several suggestions can be made for future development. The drying system can be developed further by adding a Fuzzy Logic temperature-control method so that the temperature inside the drying chamber becomes more stable and the drying process more optimal. The monitoring system can be developed using a mobile- or web-based application so that the temperature and humidity monitoring process can be carried out with a more interactive and user-friendly display. Finally, the capacity of the drying cabinet can be enlarged so that it can accommodate more clothes, shoes, and helmets within a single drying process.

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