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Designing an Automatic Dehumidifier System for Controlled Environments

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Abstract

Water stress studies are basically based on the principle of controlled reduction of the applied amount. Although water stress studies applied in field conditions give results with sufficient accuracy, they may vary due to exposure of external factors. For this reason, conducting studies in a controlled environment influences increasing the reliability of the results. In a controlled environment, factors other than the amount of irrigation water (light intensity, exposure time, growing media, air temperature, relative humidity, wind, diseases, pests, etc.) should be equal. However, relative humidity, one of these factors, is often overlooked. There are units used to remove moisture from the controlled environment. However, these units are less preferable due to their high cost and maintenance requirement. Today, rapidly developing technology has led to the introduction of various microprocessor development units. Based on this, an automatic moisture removal system was developed for an existing controlled environment (Crop Stress Monitoring and Thermography Laboratory, ÇOMÜ Faculty of Agriculture, Çanakkale, Turkey). The system built on the Arduino UNO microprocessor unit can start and stop an aspirator fan with a diameter of 35 cm at the changeable humidity and temperature limit values, according to the DHT11 temperature humidity sensor data. The system, which includes laboratory-specific design and software, allows the limit values to be changed thanks to a touchscreen on it. In this way, the relative humidity and temperature limit values required for different growing media (sand, clay, silt, peat, perlite, etc.) and plants can be adjusted. The cost of the system with all its components is around $200, which shows that it can be easily integrated into existing growing environments.

Keywords: Arduino, Dehumidifier, Evapotranspiration, Humidity Sensor, System Design

I. Introduction

The rapid growth of the global population, combined with the decline of freshwater resources and the adverse impacts of climate change, has made it increasingly necessary to develop sustainable and efficient strategies in agricultural production systems [1]. In this context, controlled environment facilities such as growth chambers, greenhouses, and plant factories provide researchers with the opportunity to apply and monitor crop stress conditions under highly regulated circumstances [2]. By isolating experimental units from external environmental fluctuations, controlled environments allow for a more precise evaluation of the effects of individual variables on plant growth and productivity. This level of control is particularly important in irrigation and water-use efficiency studies, where the reduction of irrigation water must be applied in a manner that is both consistent and scientifically reliable [3,4]. The importance of such studies continues to increase as agriculture faces new challenges linked to desertification, soil degradation, and the pressure to enhance crop yields to meet the demands of a growing global population [5].

Although a wide range of environmental parameters are typically monitored in controlled environments such as light intensity, photoperiod, temperature, irrigation scheduling, and air circulation, the role of relative humidity (RH) is often underestimated [6]. However, relative humidity strongly influences several physiological and pathological processes in plants, including transpiration, stomatal regulation, nutrient uptake, and disease development [7,8]. Maintaining an optimal humidity range is also essential for stabilizing the vapor pressure deficit (VPD), which directly affects evapotranspiration rates and plant water balance. Despite its significance, humidity regulation systems are frequently overlooked in agricultural research, largely due to their high market cost, complex maintenance requirements, and incompatibility with small-scale research facilities. Commercial dehumidifiers, while effective, are generally designed for industrial use and therefore present economic and technical barriers when applied in experimental crop growth environments [9,10].

To address these limitations, the present study focuses on the design and implementation of a low-cost and easily adaptable automatic dehumidification system specifically tailored for controlled agricultural environments. The proposed system integrates an Arduino UNO microcontroller, a DHT11 digital temperature and humidity sensor, and a 35 cm diameter exhaust fan, all of which are coordinated through a custom-developed software interface. A key feature of the system is its touchscreen-based control unit, which enables users to adjust the threshold values for temperature and humidity according to the requirements of different crops and substrates (e.g., sand, clay, peat, perlite). This level of flexibility is expected to enhance the applicability of the system in a variety of experimental setups [11]. With an overall material cost of approximately 200 USD, the system provides an economically viable alternative to commercial units, while maintaining accuracy and operational reliability. Consequently, it can be seamlessly integrated into ongoing research activities in controlled environments, contributing to both cost-efficiency and the reproducibility of experimental results. Furthermore, by democratizing access to humidity regulation technology, this study offers a valuable tool for researchers aiming to generate high-quality data in plant physiology and crop stress studies under controlled conditions.

The specific objectives of this study were threefold. First, design and construct an automatic humidity control system that could be effectively integrated into existing controlled environments without requiring substantial financial investment or technical expertise. Second, to evaluate the performance and reliability of the system under varying humidity and temperature thresholds, and to validate its accuracy against a commercial temperature–humidity logger. Finally, to assess the cost-effectiveness, usability, and long-term stability of the proposed design, thereby demonstrating its potential to serve as a practical and scalable solution for researchers conducting water stress and crop physiology studies.

II. Materials and Methods

A. Experimental Site and Controlled Environment

The study was carried out at the Crop Stress Monitoring and Thermography Laboratory of the Faculty of Agriculture, Çanakkale Onsekiz Mart University (ÇOMÜ), Turkey (Figure 1). The laboratory was designed to provide controlled environmental conditions where external influences such as wind, rainfall, and uncontrolled temperature fluctuations are minimized. The experimental setup was placed in an enclosed growth chamber that allowed the manipulation of environmental parameters including light, air temperature, irrigation regime, and relative humidity. The chamber served as a test platform for the operation and validation of the automatic dehumidification system developed in this study.

Figure 1. System Setup in Controlled Environment

B. Hardware Components

The automatic humidity control system was built using a set of low-cost and readily available electronic (Table 1) and mechanical components:

Table 1. Hardware Specifications

Component	Model/Type	Technical Specifications	Function
Microcontroller	Arduino UNO (R3)	16 MHz, 32 KB Flash, open-source	System control
Sensor	DHT11	0–50 °C ±2 °C, 20–90 %RH ±5 %RH	Temperature and humidity sensing
Fan Unit	Exhaust Fan (Ø35)	220 V AC, ~50 W, single speed	Dehumidification process
Relay Module	1-Channel Relay	5 V DC control, 220 V AC switching	Fan control
Touchscreen	2.8" TFT LCD	Serial communication, user interface	Limit adjustment and display

Microcontroller Unit: An Arduino UNO Rev3 (Arduino LLC, Italy) was used as the central processing unit. The board operates at a clock speed of 16 MHz, includes 14 digital input/output pins, and provides sufficient processing capacity for sensor data acquisition and control logic [12].

Humidity and Temperature Sensor: A DHT11 digital sensor was integrated for continuous monitoring of air temperature and relative humidity. The sensor operates within the ranges of 0–50 °C for temperature and 20–90% for relative humidity, with an accuracy of ±2 °C and ±5% RH. Pre-calibration at the factory level ensures stable performance in laboratory applications [13].

Ventilation Unit: A 35 cm diameter exhaust fan was connected to the microcontroller through a relay module. The fan was responsible for expelling humid air from the chamber whenever humidity exceeded the user-defined threshold.

Relay Module: A single channel 5V DC relay was used to control the switching of the fan at 220 V AC. This allowed the Arduino board to safely manage the high-voltage power supply of the ventilation system.

Touchscreen Interface: A 2.8-inch TFT LCD touchscreen was implemented as the user interface. The screen displayed real-time measurements of temperature and humidity and allowed users to define upper and lower threshold values. Manual override options were also available through the interface.

Supporting Components: Standard jumper wires, power adapters, and connectors were used to establish secure and stable communication between the hardware components.

C. Software Development and System Design

The control software was developed in the Arduino IDE environment. The program was structured to read temperature and humidity data from the DHT11 sensor at fixed intervals of one minute. The data were compared against pre-defined threshold values entered by the user.

If the measured humidity exceeded the set upper limit, the relay module was activated, and the exhaust fan was switched on automatically.

Once humidity dropped below the lower limit, the relay module disconnected the fan, thereby stabilizing the chamber environment.

The touchscreen allowed the operator to adjust threshold values dynamically according to experimental needs, such as growing medium type (sand, clay, silt, peat, perlite) or crop species under investigation.

A manual override option ensured that the fan could be turned on or off independently of the automated program when required (Figure 2).

The entire system was validated for stability and accuracy through repeated on-off cycles and threshold adjustments.

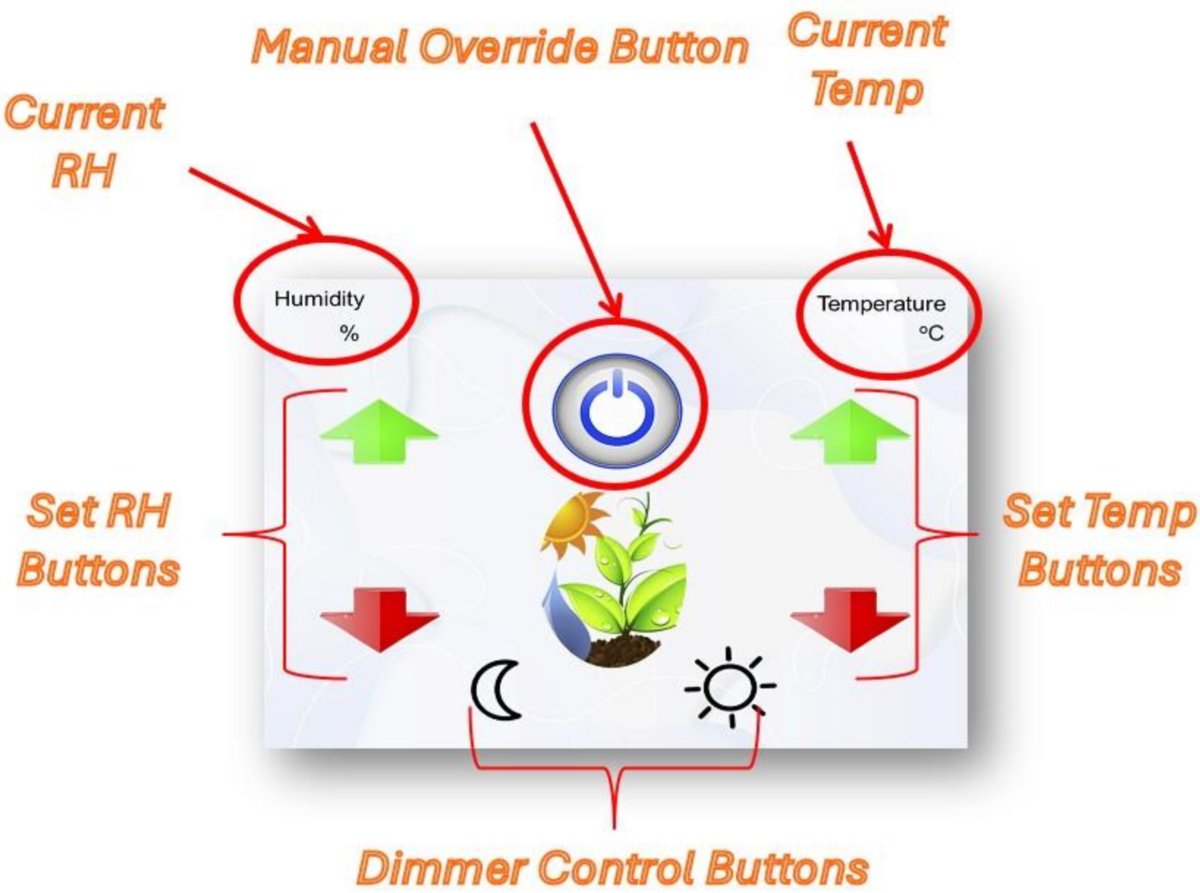

Figure 2. Touchscreen Interface

D. Experimental Protocol and Validation Tests

To assess the performance of the developed system, a series of laboratory tests (Table 2) were conducted:

Table 2. Experimental Test Procedures

Test Type	Objective	Method	Measuring Instrument	Duration
Functional Test	To check the compatibility of system units	Fan and sensor response	Arduino serial port + touchscreen	1 day
Accuracy Test	To verify measurement accuracy	Temperature and humidity comparison	Commercial Logger (±1%RH, ±0.5 °C)	3 days
Long-Term Test	To observe durability and stability	Continuous humidity control	System recordings (1-hour intervals)	3–4 weeks

Functional Test: The basic compatibility of hardware components was evaluated by running the system under laboratory conditions and confirming the real-time operation of the fan in response to humidity fluctuations.

Accuracy Test: Measurements from the DHT11 sensor were cross-validated with a commercial temperature–humidity data logger (±0.5 °C and ±1% RH accuracy). The comparison was performed under identical environmental conditions over a three-day monitoring period.

Long-Term Performance Test: The system was operated continuously for several weeks under varying threshold levels to assess stability, reliability, and responsiveness. Humidity and temperature data were logged at one-hour intervals, enabling detailed evaluation of the system's ability to maintain conditions within defined ranges.

E. Data Processing and Analysis

Raw sensor data and logger readings were exported into spreadsheets for statistical analysis. Outlier values caused by sudden disturbances (e.g., chamber door opening, sensor misreadings) were identified and excluded from the main dataset. Basic descriptive statistics (mean, minimum, maximum, standard deviation) were calculated for both temperature and relative humidity. The performance of the system was further evaluated by comparing measured values with the target threshold ranges defined in the experiments.

III. Results and Discussion

A. System Functionality and Response

The developed dehumidification system successfully demonstrated the ability to regulate humidity within the predefined threshold values. During the functional tests, the exhaust fan was activated promptly when the relative humidity exceeded the set limit and was deactivated once the environment stabilized within the lower threshold. The responsiveness of the relay–fan mechanism was consistent across multiple cycles, indicating reliable integration between the hardware components and the control software. The touchscreen interface provided a user-friendly means of modifying threshold values in real time, which allowed rapid adaptation to different crop and substrate requirements.

B. Temperature and Humidity Dynamics

Figure 3 illustrates the time-series variation of relative humidity across consecutive measurements.

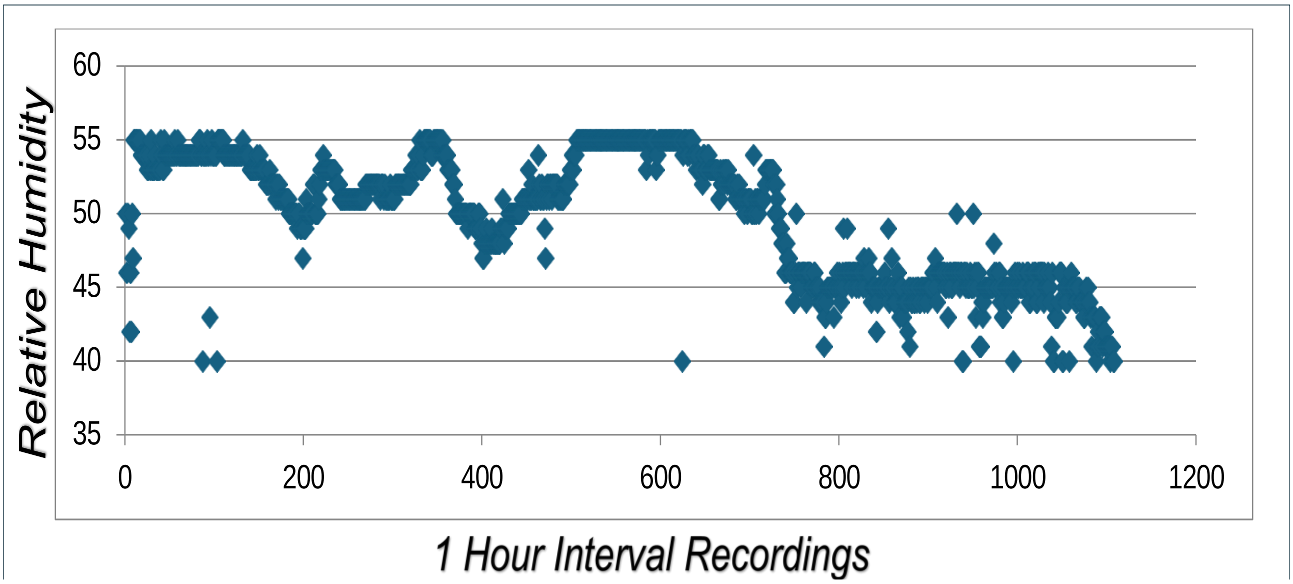

Figure3. Indoor RH Recordings by Commercial Logger

In general, temperature values remained relatively stable between 19.8–20.5 °C, with occasional outliers reaching above 23 °C. Relative humidity was mostly maintained between 55–45%, indicating effective regulation by the system. However, sporadic deviations were observed, including unusually low RH values (3–4%), which likely resulted from sensor misreadings or sudden environmental disturbances such as opening of the chamber door.

C. Validation Against Commercial Logger

To validate the accuracy of the DHT11 sensor measurements, parallel observations were conducted using a commercial temperature–humidity logger with higher precision. The comparison showed a strong correlation ($R^2 > 0.9$) between the Arduino-based system and the logger, although slight discrepancies were evident in relative humidity readings at extreme values. These variations can be attributed to the limited resolution of the DHT11 sensor, which has a tolerance of ±5% RH. Despite these minor differences, the results confirmed that the developed system provided sufficiently accurate measurements for research purposes in controlled environments.

D. Long-Term Stability and Reliability

Continuous operation of the system over several weeks demonstrated stable performance. The automatic on–off cycles of the exhaust fan effectively maintained humidity levels within the defined range, even under fluctuating environmental conditions. Cost-effectiveness was also a significant advantage, as the total material cost of approximately 200 USD is substantially lower than that of commercially available dehumidification units. Moreover, the low energy consumption of the fan and the simplicity of the microcontroller-based system further enhance its suitability for prolonged experimental use.

E. Comparison with Previous Studies

The findings of this study are consistent with earlier reports emphasizing the importance of humidity control in plant growth environments. Reference [8] highlighted that inappropriate humidity management can lead to excessive transpiration or increased disease incidence, while [9] demonstrated the technical complexity of conventional dehumidification systems in greenhouses. In contrast, the system developed in the present study offers a simpler, low-cost solution that can be readily adapted for small-scale laboratories or greenhouses. Although its accuracy is somewhat limited compared to advanced sensors, its operational performance makes it an attractive alternative for experimental applications.

F. Limitations and Future Improvements

Despite the encouraging results, several limitations should be noted. The DHT11 sensor provides relatively coarse resolution, which may reduce accuracy in experiments requiring highly precise humidity measurements. Additionally, the system is currently limited to dehumidification through forced ventilation; future enhancements could incorporate dual functions of humidification and dehumidification to ensure more comprehensive climate control. Integrating the system with IoT-based data logging and remote monitoring platforms would also allow continuous data storage, cloud-based analysis, and real-time remote control, thereby expanding its practical utility in advanced research applications.

IV. Conclusion

This study presented the design, development, and evaluation of a low-cost automatic dehumidification system for controlled agricultural environments. By integrating an Arduino UNO microcontroller, a DHT11 temperature–humidity sensor, a relay module, and a 35 cm exhaust fan, the system effectively regulated relative humidity within predefined thresholds. Validation against a commercial logger demonstrated that the accuracy of the system was sufficient for experimental applications, while long-term operation confirmed its stability and reliability.

The major advantage of the system lies in its affordability and adaptability. With a total cost of approximately 200 USD, the system provides an economical alternative to commercial dehumidifiers, which are often prohibitively expensive for small-scale laboratories and research facilities. Furthermore, the touchscreen interface allows flexible adjustment of threshold values, making the system suitable for a wide range of crops and experimental setups.

Overall, the results indicate that the proposed design offers a practical and accessible solution for researchers seeking to improve the precision of humidity management in controlled environments. Future work should focus on incorporating more advanced sensors, expanding the system to include both humidification and dehumidification capabilities, and integrating Internet of Things (IoT) technologies for remote monitoring and data analysis. These enhancements would further increase the applicability of the system in precision agriculture and controlled environment research.

Acknowledgment

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