Automated Irrigation and Fogging System with Temperature-predictive Capability for Greenhouse Farming

Olugbenga Kayode Ogidan[1], Isaac Elesemoyo[2], and Hasan Babalola[1]

[1]Department of Electrical and Electronics Engineering, Elizade University, Ondo State, Nigeria
[2]Department of Computer Engineering, Elizade University, Ondo State, Nigeria
olugbenga.ogidan@elizadeuniversity.edu.ng

Abstract. Farmers in sub-Saharan Africa are plagued with the challenges of climate change, farmers-headers clash, resulting in low production. Greenhouse farming is seen as a way out due to small space required and ability to control microclimate. Tropical Greenhouses are usually very hot in the afternoon resulting in water and heat stress. This work develops an automated system that monitors microclimate in real-time, regulate temperature and provides prediction of future water needs to aid future management. A data acquisition system using Atmega 382 microcontroller and a DHT22 was used for monitoring and control while Raspberry Pi was used for future temperature prediction. At a threshold temperature of 30ºC, the microcontroller activates a fogging pump to release mist into the greenhouse to cool the heat-stressed leaves thus enhancing photosynthesis. Irrigation is also activated using drip system. Raspberry Pi combined with DHT22 is used to collect temperature and humidity measurement which were used to train a machine learning algorithm and stored Google sheets in the cloud. The experimental result reveals the ability of the system to perform greenhouse automation, monitoring, and control of fogging and irrigation remotely as well as temperature prediction. Machine learning models: linear regression (LR), support vector regression (SVR) and random forest regression (RFR) were trained with acquired data and the results were compared. The results revealed accuracy (RFR: 98.43%, SVR: 98.54%, LR: 98.57%), and MAE (RFR: 0.47, SVR: 0.44, LR: 0.43). The developed system will enhance greenhouse agriculture and boost food production, especially in the tropics.

Keywords: Greenhouse, Automated Irrigation, Fogging, Predictive Capability.

1 Introduction

Farmers in sub-Saharan Africa are challenged by climate change. This has manifested in form of irregular rainfall patterns resulting in lower crop yield and inability to cultivate all-year-round. This calls for the need to adopt greenhouse farming combined with irrigation and forging system. Apart from the fact that greenhouses occupy smaller area, it helps to Screen-off other factors that inhibit crop performance such as pests, and diseases. It has been found to have higher crop yield compared to open-field cultivation and enable s the farmer to produce crops all-year round. Despite the benefits of greenhouse farming, it his plagued with excessive heat in the afternoon, especially in the tropics. The heat are non-desirable for crops because it leads to water stress and inhibits the process of photosynthesis resulting in poor yields.

To address these challenges, this work develops an automated irrigation and fogging system to produce a conducive microclimate for crop growth to achieve optimal crop yield.

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Where there is non-availability of enough water for crop use, the farmer needs to be proactive in projecting the amount of water that would be required for crop use to plan his irrigation and fogging scheduling and provide adequate water for crop use.

This research aims at the development of a prediction scheme for an irrigation and fogging system in a farm facing the challenges of water shortage. To manage these challenges, digital twin adoption [1,2] with the Internet of Things (IoT) devices and sensors has evolved as a possible solution [3].

The historical timeline of greenhouse management reveals a rich evolution, 17th century introduction of improved glass manufacturing techniques to 19th century adoption of heating systems like coal-fired boilers. Automation systems emerged in the mid-20th century, introducing automated processes for ventilation, temperature control, and irrigation, which improved crop management and labour efficiency. This involves monitoring and control systems for precise regulation of temperature, humidity, lighting, and irrigation, ultimately enhancing crop growth conditions.

Automation now integrates sensors, actuators, and control systems to regulate environmental conditions automatically. These systems employ advanced algorithms and data-driven approaches to optimize plant growth parameters [4]. Energy-efficient technologies, including high-efficiency heating and cooling systems, energy curtains, and wireless sensor networks, have helped reduce energy consumption in greenhouse operations.

However, greenhouse management still faces challenges, including need for skilled personnel, and the constant monitoring and adjustment of multiple environmental factors. Disease and pest management remain ongoing challenges, necessitating integrated pest management strategies and constant vigilance.

To overcome these situations, digital twin technology has become a promising solution in greenhouse management [5]. Researchers have conducted various studies and practical implementations to demonstrate the effectiveness of digital twins in this context [6, 7]. The authors in [6] focused on creating an ideal controlled environment for vertical farms using smart sensors and activator devices with a Raspberry Pi. While their research emphasized monitoring and control, it lacked predictive and prescriptive capabilities.

[7] explored how artificial intelligence and sensor data can determine appropriate environmental conditions and strategies for managing greenhouse tomato production [8].

Different works reviewed in this paper demonstrate the multifaceted applications of digital twin technology [9] in greenhouse management, from real-time monitoring and predictive analysis [6,7,10]. This particular work differs from previous approaches because it combines greenhouse automation with the use of artificial intelligence for predicting ideal environmental conditions for optimal crop yield in a laboratory-scale greenhouse scenario. This is innovative in the sense that the laboratory-scale greenhouse would aid teaching and research in an infrastructural deficit settings such as Africa while the results obtained can be validated and scaled up for real-life scenarios. Arranging the rest of the paper is as follows. Section 1 introduces the project; Section 2 focuses one methodology of the project. Section 3 considers the results obtained and gives a brief discussion regarding those results while section 4 is the conclusion.

2 Methodology

The approach adopted here involves acquisition of data in real-time, monitoring and control, data storage, and predictive modeling.

2.1 Real-time Data Acquisition

This entails the gathering of temperature and humidity data of the environment continuously every 30 minutes for 3 months. To get this done a digital humidity and temperature (DHT22) sensor connected to Raspberry Pi obtains the environmental temperature and humidity of the laboratory-scale greenhouse, and sends the data to node-red which in turn sends it to a dedicated Google Sheets for storage online. Fig. 1 illustrates the architecture of the developed system.

Fig. 2a shows the interconnection of the hardware components used for data acquisition, systems automation, and predictive analysis of the obtained data. They include the DHT22 sensor with a temperature range of -40ºC and 80ºC while the humidity covers 0 to 100%. Others include Raspberry Pi, 2-channel relay used for switching pums and valves, Atmega 382 microcontroller housed by Arduino Uno board, serial cables, and so on. The fogging pump used has 24 V input voltage and 1.2 A current with a flow rate of 2.6 ML/Min. The irrigation pump is a Toyota Corolla wiper pump with 12 V input voltage and a size of 9 by 6 by 5 in terms of length, width and height. The system flowchart is shown in Fig. 2b while the laboratory-scale model of the automated greenhouse where the experiment was carried out is shown in Fig. 3. The greenhouse adopted in this work is a laboratory-scale greenhouse with a dimension of 86 cm in length, 71.5 cm in breadth, 62 cm in height of it can accommodate 15 potted onions at 15 cm distance to each other. It should be noted that this laboratory-scale greenhouse is meant to emulate a real life scenario and to be used to test the operation of the fogging system or simulating it for its implementation in a bigger greenhouse used for commercial farming.

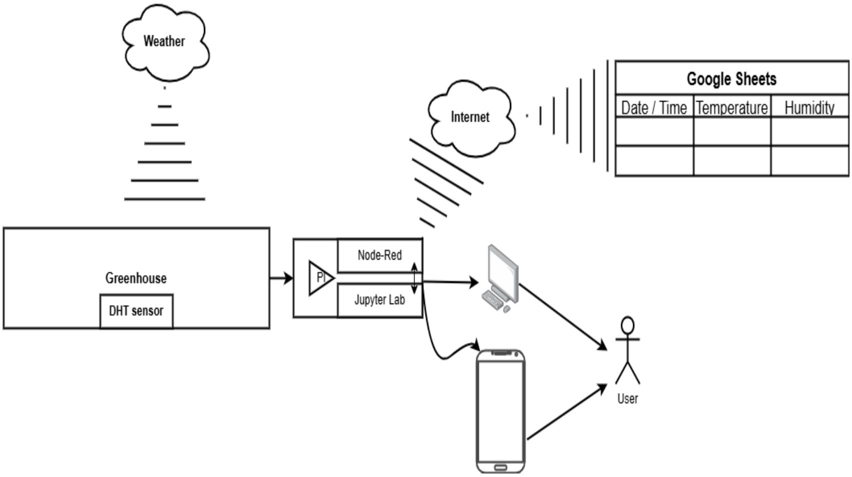

Fig. 1. System architecture illustrating data acquisition and storage process.

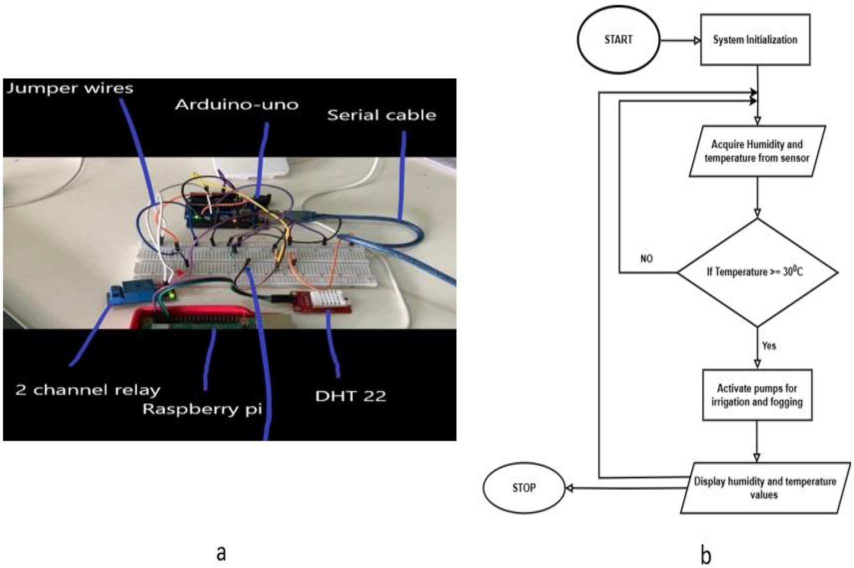

Fig. 2a. Connection of components for the greenhouse control unit **2b.** Flowchart illustrating automated irrigation and fogging operations

Fig. 3. Overall setup of the irrigation system

2.2 Data Storage

Data storage was achieved using the online Google Sheets. After data acquisition, the data has to be stored to enable easy access and computations to be carried out to understand the past and current state of the greenhouse and to use this knowledge for predicting future states. Google Sheet was created in Google Drive to serve as the data storage (database) and manipulation platform for the project. To be able to achieve this, there was an integration of Google Sheets in the Node-Red software. Each of the data stored in the Google Sheets was labeled with its date and time (time-stamped) as shown in Fig. 1.

2.3 Predictive Analysis

Jupyter Lab was used for data analysis and predictive modeling. Using the data acquired from the DHT sensor that is then connected to Raspberry Pi a predictive model was trained so that the greenhouse future temperature is determined. The mean temperature value for each day was calculated. To validate the result, using Pandas, Numpy, pi and other machine learning libraries, a linear regression was developed based on its high accuracy and low mean absolute error which was compared to support random forest regression and vector regression models..

3 Results

Experiments were carried out to evaluate system performance. Fig. 4 is the graph of a sample of the temperature as well as humidity of the greenhouse acquired using the DHT22 sensor for 30 days after which it was graphed. In terms of automatic control and real-time monitoring, Fig. 5 show DHT22 sensor data displayed in real-time on a personal computer (PC) through the user-friendly interface. The system operates in the default mode (automatic, without human intervention) and the override mode (in which the user can initiate irrigation and fogging operations by clicking on menus on the user interface). In the automatic mode, the system is read only meaning that the operator is only able to view the control operation taking place in the greenhouse autonomously. In the override mode, the automated operation can be overridden at the discretion of the operator as shown in Fig. 5b. Through the user interface, the operator is also able to monitor the weather parameters of the greenhouse such as temperature and humidity as illustrated in Fig. 5. These results show that the fogging system is capable of monitoring the temperature and humidity [9] inside the greenhouse, analyzing the data, and activating the actuators based on analysis of acquired data.

In terms of prediction, the developed model was tested to predict temperature for a specific date, which was the 14th day of May 2023 after which a result of 29.87 Celsius was obtained. Fig. 6 shows how the model was used to predict temperature for a range of dates. By creating predictive models using random forest regression (RFR), linear regression (LR), and support vector regression (SVR) models [11] on the same data, the accuracy and mean absolute error (MAE) were evaluated and compared.

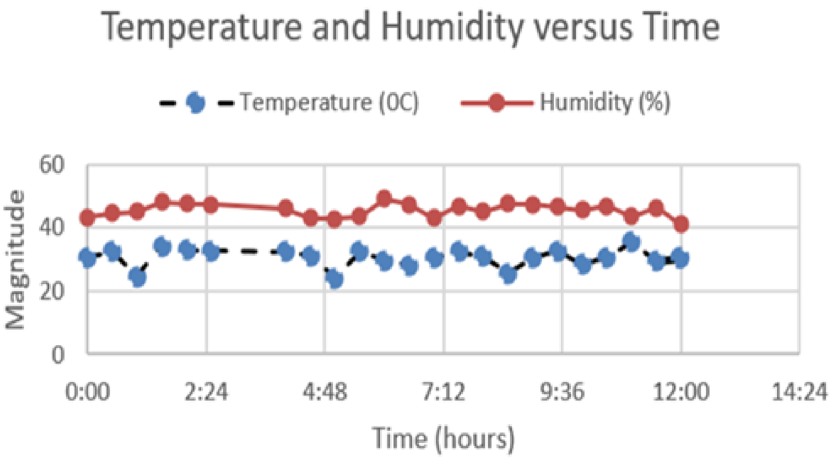

Fig. 4. Graph of Temperature and Humidity with time

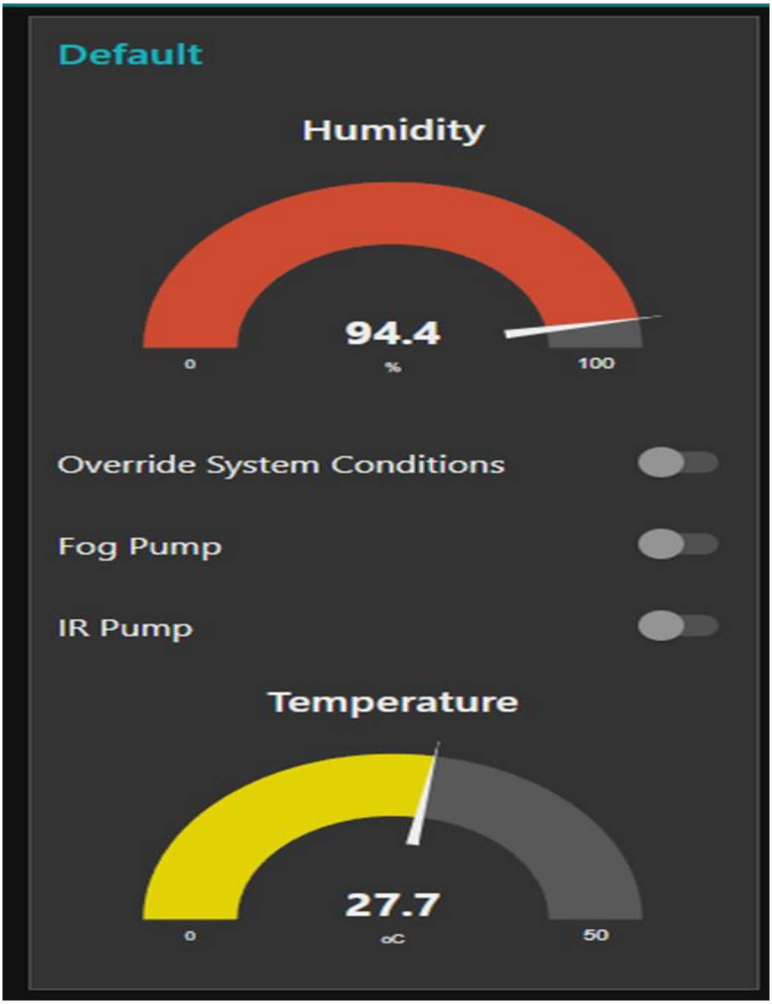

Fig. 5. Humidity and Temperature Reading

The results revealed accuracy (RFR: 98.43%, SVR: 98.54%, LR: 98.57%), and MAE (RFR: 0.47, SVR: 0.44, LR: 0.43). The result of a comparison of the three predictive

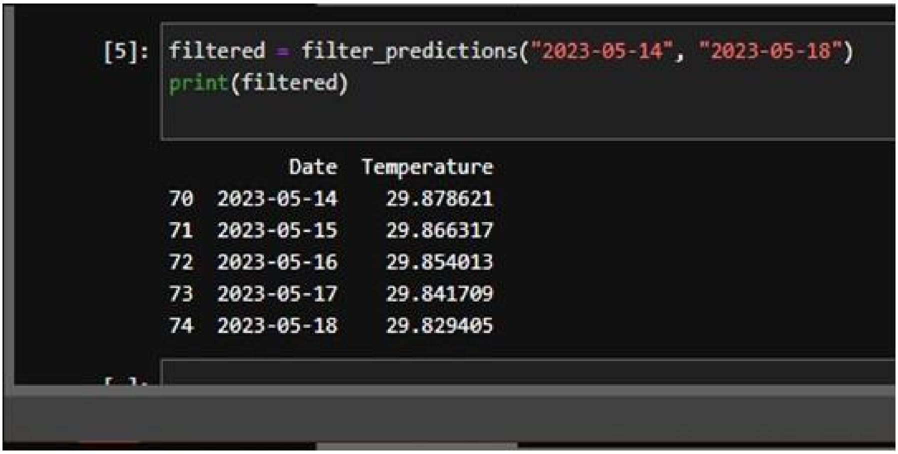

Fig. 6. Predicting temperature for a range of dates

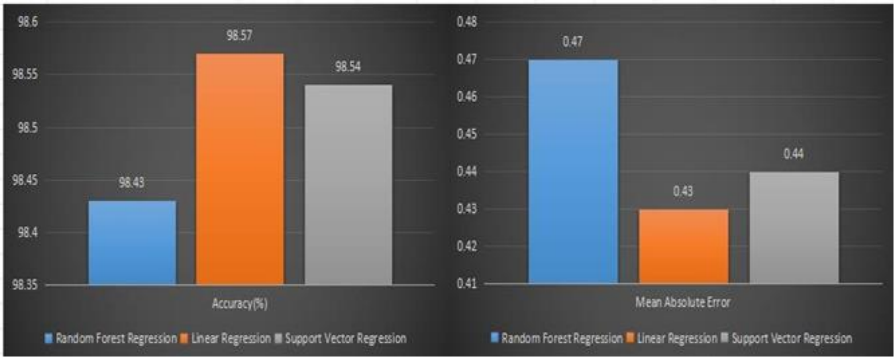

Fig. 7. Column chart of models based on Accuracy and MAE

4 Discussion of Results

From Fig. 4 and Fig. 5, one would observe that humidity and temperature are inversely proportional to each other [14 - 15]. For instance, when the humidity was 94.4 % (high), the temperature was 27.7 ºC (low). In this condition, less water will be required for the irrigation and fogging process compared to a high temperature and low humidity scenario that would require a high amount of water. This

Real-time monitoring and control of the greenhouse microclimate from remote location provides full control of the greenhouse at any time and reduces the overhead cost spent in engaging many workers [12]. Unlike the cases in [12] and [13], where the condition for automated irrigation was based on measurements of soil moisture, in this work, we found out that temperature and humidity could be an indicator to determine the need for irrigation in the absence of a soil moisture sensor especially in a greenhouse setting. Thus, this particular work is an improvement over other works in which laboratory-scale irrigation system was used [12,13] because it goes further to use predictive algorithm to estimate the future temperature with a view to proactively make provision for future water needs of the crops based on the predicted temperature and by extension humidity of the greenhouse.

The predicted temperature for a specified number of days as shown in Fig. 6 is very useful for planning and management decision that assists the operator to be able to forestall and mitigate unfavorable weather while keeping the greenhouse at optimal condition. Comparing the three predictive models reveals that RFR was lowest in accuracy (98.43 %) but with the highest performance in MAE (0.47 %) while LR was highest in terms of accuracy (98.57%) but lowest in LR (0.43 %).

5 Conclusion

A laboratory-scale greenhouse was developed and equipped with automation and predictive capabilities to aid a greenhouse manager in remotely monitoring and controlling the environmental conditions of the system. Automated fogging and irrigation as well as real-time monitoring was achieved through a user-friendly interface. The system could predict future temperature to aid planning and managing greenhouse microclimate for conditions favourable for the plants. Future work would involve the prediction of crop water requirements for specific crops based on environmental data obtained from sensors as well as the power required to keep the system running and scaling up the system to real-life greenhouse farms.

Disclosure of Interests. The authors have no competing interests.

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