Automated Climate Monitoring System: the Case of Greenhouse Industries in Ethiopia

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A B S T R A C T

Technological interventions can play a significant role to keep optimal growing conditions in greenhouse industries with varying seasons and improve environmental performance by maintaining heating, cooling, and humidity levels. The research reported in this paper aims to integrate an Automated Climate Monitoring System (ACMS) for greenhouse in Ethiopia. Green- houses in Ethiopia require constant monitoring to properly maintain optimal climate conditions to grow plants all year round. To this end, they apply environment monitoring systems like timing devices, ON/OFF controllers and manual (human) monitoring which are prone to error. We propose a flexible ACMS prototype which can be applied without a user having the knowledge of how the system is made. The prototype system uses Advantech PC- cards and maintains the optimal climate condition (temperature, humidity and light intensity) of the greenhouses. Moreover, the easy to use graphical user interface provided by the system enables to combine the hardware and software functionalities for optimal manipulation of the environmental conditions. The system is centralized in that anyone can control several de- vices spread in the environment being monitored from one Computer. The performance of the system is found to be 88.89% which is "accurate and acceptable" result according to our confusion matrix. This indicates that better environmental supervision can be achieved when using the system. Moreover, the mean user acceptance (by the flower growers) of the ACMS and timing devices, ON/OFF implementations is 84.6% and 73.2%, respectively, highlighting the potential for integrating the ACMS into the greenhouse industry.

Keywords:
Automation
Greenhouse
Climate Control
Sensors
Temperature
Light
ACMS

1. Introduction

A greenhouse is an area designed to grow plants, which allows optimum growth and takes care of maintaining a protected environment despite fluctuations of external climate [1]. Many greenhouse industries in Ethiopia ap- ply climate monitoring by using mechanisms like Timing Devices, ON/OFF Controller and Human Monitoring [2, 3, 4]. In line with this, programmable monitoring devices have played a vital role for greenhouse industries, becoming an important and integral

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part of modern manufacturing and industrial processes [5]. Moreover, it becomes essential for greenhouse operations as monitoring pressure, temperature, humidity, light intensity and flow in the industrial process [6].

The greenhouse climate is most important for protecting environmental conditions of a plant. By monitoring and controlling the above climate conditions plants will be in the most favorable condition to grow. To do so, we must take advantage of the latest technologies like applying programmable climate monitoring devices, which refers to maintaining the optimal climate conditions using chipsets [5]. In the research reported here, climate condition is supervised by Automated Climate Monitoring System (ACMS), which uses Advantech PC-cards. The proposed System has an easy to use Graphical User Interface (GUI), which the user can enter the desired values for the different parameters that are going to be monitored. GUI is a user-friendly program through which a user passes instruction for the installed devices to perform a specific task [7].

Any changes from the desired values will be automatically compensated through devices controlled by the output of the Advantech PC-cards. Advantech PC-cards are interfaced to the Computer and programmed using the PHP programming language [8]. In our research, we used PCL-818L and PCLD-885 Advantech PCI-cards and installed Dynamic Link Library (DLL) drivers for efficient input/output management of the devices. The DLL files represent the application programming interface (API) for the drivers. The actuating element in our research has only two fixed positions which are ON/OFF controller. The ON/OFF controller is simple yet inexpensive, and as a result it is widely used in both industrial and domestic control systems [9].

Our prototype system is developed using Web technologies for ease of monitoring multiple locations of the greenhouse from one central location via the Internet (thus Internet of Things). Therefore, integration of an ACMS with the greenhouse industries can help address problems more effectively and economically. The remainder of the paper is organized as follows. Section 2 provides a review of the state-of-the-art in ACMSs of various phenomenon, and industries. In Section 3, we present the research methodology describing the experimental setup, tools, and various sensing devices used in the study. In section 4, the conceptual framework and prototype system implementation are described. Evaluation results are presented in Section 5, while Section 6 concludes the paper.

2. Related Work

The review of related literature was performed focusing on setting up the motivational aspects relating to the study domain. The following are among the studies undertaken towards climate controlling and monitoring systems in the area of greenhouse industries. Accordingly, in Spain Perez et al. [10] presents automation for climate conditions of a greenhouse based on a Programmable Logic Controller connected to a group of sensors and actuators. However, Perez et al. did not mention the architecture to the designed system and the performance of the automated system is left unknown.

In addition, the climate models mentioned in this paper still require further improvement. Research conducted in Asia by Pahuja et al. [11] discusses the implementation of greenhouse climate simulator under open and closed control conditions. Simulations were performed which indicate a high performance of the controller in regulating crops. However, the performance result is obtained from a simulation experiment employing relatively few climate parameters. In addition, there is an absence of human to computer interaction performance evaluation. Therefore, the above paper requires analytical evaluation among human experts, users and the simulator. The Korean Society for Bio-Environment Control together with Kim et al. [12] conducted a study to develop a system and algorithm for controlling the environment of a plant factory. While light is an essential factor in maintaining plants [13], Kim et al. lacks sensing the light at the greenhouses (i.e. they did not deal with the model of light as input to their research).

Moreover, very little cases were incorporated during system testing. As such, one can enhance the performance of the system by adding more cases. Additionally, the algorithms must be modified in order to solve the green- house problems. Gomez-Melendez et al. [14] had also proposed development of a fuzzy irrigation system based on a field programmable gate array (FPGA) to monitor the greenhouse. The design, compilation, and simulation of the system mainly focus on hardware and circuit devices i.e. human power needs to be present to adjust the climate monitoring. This becomes difficult for ordinary greenhouse workers to interact with the system, because it is not user friendly and not simple to implement a fuzzy logic controller system. Soto-Zarazua et al. [15], in work implemented in Mexico, presents recently developed applied approaches for climate control in greenhouse as well as modern trends in algorithm usage. Consequently, a greenhouse climate system based on fuzzy logic is offered. The system uses only temperature and relative humidity as input parameters. However, Ahonen et al. [16] articulates temperature, humidity and light are the most important input factors for a greenhouse. Accordingly, Soto-Zarazua et al. did not address the concept of Light as input to greenhouse environment.

To conclude, the above studies have been made using Programmable Controller Technique to find out solutions to climate condition problems and are found to have shortcomings when applied to greenhouse industries. More- over, our review of the literature [2, 3, 4] and on-site physical observation indicated that many Ethiopian greenhouse industries maintain climate condition using timing devices, ON/OFF controller and manually. Thus, our study focuses on exploring the impact of using automatic control technologies in the greenhouse industry to address certain limitations of the previous studies (e.g., improving efficiency, accuracy, and ease of access) in the context of the climate condition in Ethiopia.

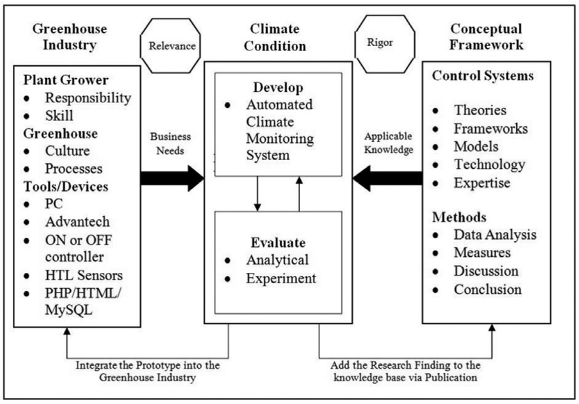

Figure 1. The Research Methodology.

3. Methodology

Our research methodology is modified from the design science research (a method which involves the application, testing, modification and extension of existing theories [17] through experience, creativity, intuition, and problem- solving skills of the researchers) as shown in Fig. 1 below.

In Fig. 1 below [left] the greenhouse research environment is composed of Plant Growers, Greenhouse processes, and tools/devices. [On the middle] a prototype system was designed, developed and evaluated for the purpose of providing deeper insights into the situation of the existing greenhouse problems. The developed prototype system itself was used as a research object, later to be integrated into the greenhouse industry. Finally, [right] the existing foundations and methods about climate monitoring system are applied into our research.

3.1. Procedure

This research adheres to Design Science guidelines [17], according to which the roles and techniques applied in our methodology (see Fig. 1), are specified in the following procedures. Firstly, a literature review and on- site industry observation was performed to recognize the Problem Relevance. As per our findings, many Ethiopian greenhouse industries apply supervision by using mechanisms like Timing Devices, ON/OFF Controller and Human Monitoring which are prone to failure due to error, device difficulty and un- availability.

Next, an ACMS was designed and developed as a prototype system in order to solve the industry problems mentioned above. Then, an effective Conceptual Framework was utilized to reach desired ends by the prototype system while satisfying foundations of monitoring systems and data measurement techniques.

The quality and value of the developed prototype system was rigorously evaluated via analytical and experimental methods. As a result, a much better environment monitoring is maintained by our re- search prototype system compared to the existing activities carried out at the greenhouse industry. Finally, the findings of this research are communicated successfully through this paper to the rest of technology audiences.

3.2. Sampling

During this study, there are one hundred thirty active greenhouse growers in Ethiopia [11]. Nineteen of these are found at Tana Flora Company in Bahir-Dar. Tana Flora Company was taken as a case and six (6) skilled and experienced horticulture experts are purposefully selected by the researchers for evaluating the performance of the prototype system.

User acceptance was evaluated using all the 19 flower growers (We consider only those involved in growing flowers and excluded other employees like sales, finance, and procurement) found at Tana Flora Company. The reason for taking the whole population size (the 19 growers) as our sample is according to the Solvin's formula provided next (see Stephanie [18]):

$$\frac{N}{1 + N * e^2}$$

Where n = sample size, N = total population and e = 0.05. Using the above formula, we get approximately 19 samples of flower growers selected (out of the 19 growers) who participated as user acceptance evaluators. The users participated to access and interact with the proposed ACMS system, timing devices and ON/OFF controllers.

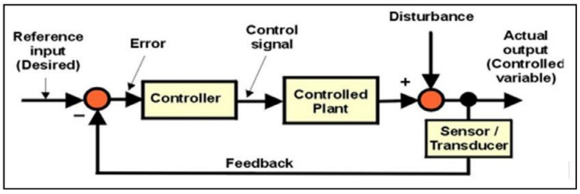

Figure 2. The Proposed Feedback Control System.

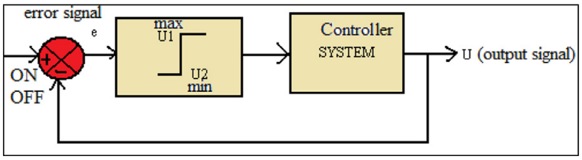

Figure 3. The Proposed Two-Position (ON/OFF) Controller.

3.3. Tools and Devices

We employed software libraries (DLL) to specify the communications protocol between peripheral devices (sensor, PC-Cards and Relay board) and the Computer [19, 20]. We used Advantech PCL-818L and PCLD-885- PCI (Peripheral Component Interconnect)-cards and installed the integrated Advantech driver information. Next, a 32-bit Windows-7 and DLL file was pre- pared for communication between the host computer and Advantech data acquisition setup.

Finally, a GUI has been developed which allows a user to monitor the status and interact with the various hardware devices [7]. The interface is developed using Web technologies (PHP and HTML) and MySQL database to monitor multiple locations of the greenhouse by leveraging the Internet infrastructure (as Internet of Things) [21]. The PHP, HTML and MySQL pack have been particularly selected because of their compatibility to implement with Advantech.

4. Conceptual Framework and Prototype Implementation

4.1. Conceptual Framework

4.1.1. Control Systems

The types of control systems are Feedback control system, Closed-loop control system and Open-loop control system [22, 23]. We found the Feed- back control system to be suitable to this research problem, because Users/Plant- Growers require constant feedback from the environment to properly maintain optimal climate conditions of plants.

An example would be a room- temperature control system in the greenhouse industries. By measuring the actual room temperature and comparing it with the reference temperature, the thermostat turns the heating or cooling equipment ON/OFF Controllers to ensure that the room temperature remains at a comfortable level regardless of outside conditions (see Fig. 2).

4.1.2. Classifications of Controllers

Controllers are classified according to their control action as Two-position or ON/OFF Controllers, Proportional con- trollers, Integral controllers, Proportional- plus-integral controllers (PI), Proportional-plus-derivative controllers (PD) and proportional-plus-integral-plus-derivative controllers (PID) [24, 25].

In our case a Two-position or ON/OFF controller is found to be suitable to this research, being widely used in industrial control systems (see Fig. 3). Moreover, it is simple and inexpensive to apply in this research. The Two- position or ON/OFF Controller was embedded with the proposed research using GUI application.

4.2. Prototype architecture and sensors

As shown in Fig. 4, the task of our architecture is to activate an actuator using sensor, drive the output devices with the help of PCLD-885 board and keep the climate in the greenhouse as desired using PCL-818LPC card. We integrated PHP based GUI code into the architecture for letting a user to automate devices by using ON/OFF Controller easily. So, upon the request of the user, the Computer combines the work of the hardware devices (Sensor, PC-Cards and Relay board) and software parts (Driver, PHP Application) to provide an optimal range of environmental conditions for the greenhouse industries.

Humidity, Temperature, and Light intensity were used as climatic conditions to be monitored in the greenhouse industry. Each of these is described next: Humidity refers to the water vapor content in air or other gases. Humidity measurement can be stated in a variety of terms and units i.e. Ab- solute Humidity, Dew Point and Relative Humidity (RH). RH refers to

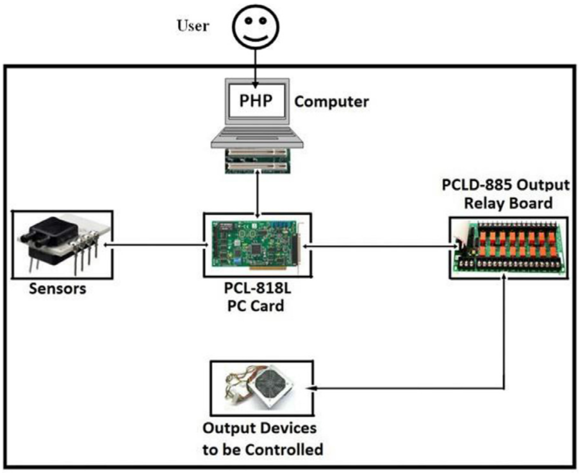

Figure 4. Architecture of the Prototype.

the ratio of the moisture content of air compared to the saturated moisture level at the same temperature and pressure [26]. Therefore, RH is selected in our research because of its greater accuracy, lower cost and dependability.

The temperature control provides the required heat or avoids the un- necessary heat that means cooling [27]. In this research, the heat output operates when the temperature falls below the minimum heating temperature settings; separate settings for day and night are provided. The ventilation output is monitored by temperature, humidity and cycle timers. It operates when the temperature falls above the maximum set temperature.

The rate of growth and length of time a plant remains active is dependent on the amount (intensity) of light it receives. So, light energy is used in this research, the plant's most basic metabolic process [13]. Thus, for the accomplishment of this research we employed different sensors. The major sensor types employed in this research were:

Humidity Sensor. Also called a moisture sensor, it is used to sense mois- ture of the environment inside the greenhouse [28]. RH sensor is selected to our research because of its greater accuracy, lower cost and its reliability comparing to others. The response time of RH is 10 to 30 sec for a 63% step change. The nominal operating temperature is 40 to 100 degree centigrade. Moreover, the distinct advantage of RH is its interchangeability.

Temperature Sensor. Thermistors, digital thermostat and the LM35 sen- sors are investigated here. Thermistors are not selected in our work because of the non-linear characteristics of the signal over wide temperature ranges (0 to 30 degree centigrade) [29]. The Digital Thermometer is selected to be used as a junction for the sensors and actuators which is programmed before it is inserted into the prototype system. In addition, a LM35 Temperature Sensor is also selected, whose output voltage is linearly proportional to the Celsius temperature [30].

Light Sensor. While the rate of growth and length of time a flower remains active is dependent on the amount of light it receives [31], the Light Sensor in this research monitors light intensity of the flower around the greenhouse environment.

4.3. Prototype implementation

According to the flowchart shown in Fig. 5, the user interface has software modules used to perform the user's request. Upon the requests of the user (see Fig. 6) the forms written with PHP redirect instructions from form to form and finally to the devices installed to perform operations. The PC- cards installed will receive instructions from the user to perform the required monitoring purpose. PC-Cards are chipsets which are interfaced to the Computer and integrated using PHP codes and we have applied the Graphical User Interface shown in Fig. 6.

The following procedure is applied when using the prototype system. Firstly, the prototype asks the user to enter all the necessary values and parameters that are going to be used throughout the process (see Fig. 6). Next, users confirm the values entered before going to the actual monitoring processes. Then, the device selection module searches for the type of devices installed. This module will read the devices installed along with the assigned gain value and the input channels. Finally, the computer starts the green house automation process by taking the values inserted (see Fig. 7). The greenhouse automation process also selects the output port. Here, different colors are also used to differentiate among the different states.

4.4. Greenhouse Automation Process

In this research, we have divided the greenhouse automation process into three categories i.e. Temperature, Light intensity and Humidity. These categories are discussed in detail below.

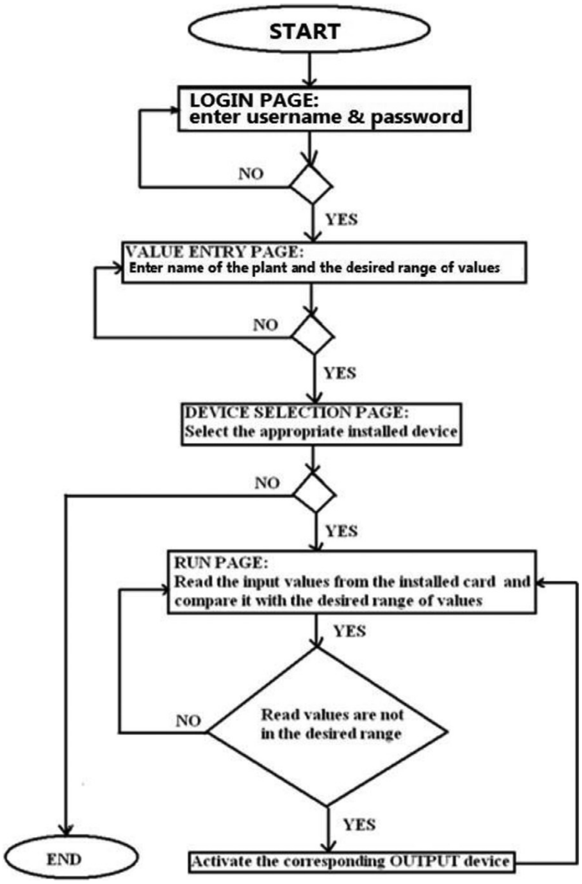

Figure 5. A Flowchart of the Prototype System.

Temperature Level. Here, the value of the input temperature reading is converted to the scale selected by the user. Next, the required day and night temperature range for the flower is displayed (see Fig. 7). We have written a PHP code that frequently scans the clock of the computer and it selects the day or night temperature requirements based on the current condition. There are three possible output states in the green house automation process explained as the following.

1) If the current sensor reading shows that the temperature is in the range between the maximum and minimum temperature requirements, a text "Normal temperature" will be displayed with green background and both the heater and fan will be OFF.
2) If the current sensor reading shows that the temperature is below the minimum temperature requirement, a text "Low temperature, heater ON" will be displayed with yellow background and the heater will be ON.
3) If the current sensor reading shows that the temperature is above the maximum temperature requirement, a text "High temperature, fan ON" will be displayed with red background and the fan will be ON.

Light Intensity. In this category, the value of the input light intensity reading and the required range for the flower will be displayed. Only the minimum temperature requirement is taken into consideration, because, it is almost impractical to monitor such a condition and the possible source of light when the lamp is OFF is the Sun. The state of the output devices is displayed at this label in Fig. 7. There are two possible output states.

1) If the current sensor reading shows that the intensity is above the minimum intensity requirement, a text "Normal light intensity" will be displayed with green background and both the lamp will be OFF.
2) If the current sensor reading shows that the temperature is below the minimum intensity requirement, a text "Low light intensity, lamp ON" will be displayed with yellow background and the lamp will be ON.

Humidity Level. The value of the input humidity reading is displayed as shown in Fig. 7. Here, the required humidity range for the flower will be displayed. Thus depending on these values, the output devices will be monitored. There are three possible states of the output devices displayed at this label.

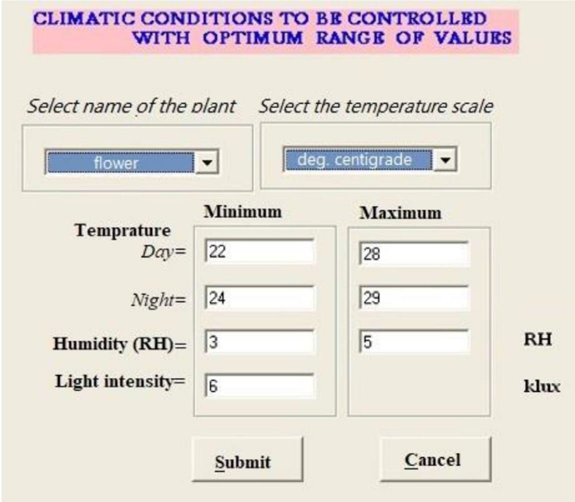

Figure 6. Main Page of the Graphical User Interface.

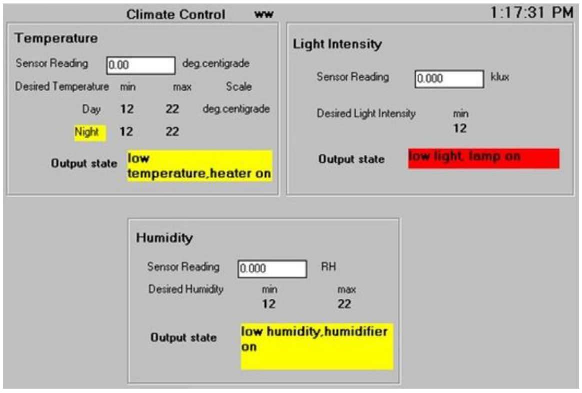

Figure 7. Screenshot of Greenhouse Automation Process.

1) If the current sensor reading shows that the humidity is in the range between the maximum and minimum temperature requirements, a text "Nor- mal humidity" will be displayed with green background and both the humid- ifier and dehumidifier will be OFF.
2) If the current sensor reading shows that the humidity is below the minimum humidity requirement, a text "Low humidity, humidifier ON" will be displayed with yellow background and the humidifier will be ON.
3) If the current sensor reading shows that the humidity is above the maximum humidity requirement, a text "High humidity, dehumidifier ON" is displayed with Red background and the dehumidifier is ON.

5. Results

5.1. System Performance Evaluation

System performance evaluation is the process of determining whether the developed prototype system meets the level of accuracy as required and validates whether the right prototype has been built [32]. We have applied this method to evaluate the accuracy of the prototype system using the parameters precision, recall and F-measure.

In this research, eighteen (18) flower test cases are formulated by the horticulture experts as shown in Table 1 above. First, these test cases are distributed equally to the six (6) purposefully selected evaluators. In the process of testing, the horticulture experts organize the cases as correctly and incorrectly classified cases.

The evaluators are also given a "Result Summary Report" form. Then, after testing the prototype system against their given test cases, all eval- uators returned the "Result Summary Report" to the researchers. Next, according to the climatic condition, we divided the 18 flower cases into three as Temperature class, Light class and Humidity class by discussing with the horticulture experts. Finally, we compared the judgments reached by the prototype system with that of the evaluators.

Table 1
Eighteen (18) Flower Test Cases Formulated by Horticulture Experts.

Case No.	Case Description	Expected Answer
1	((Tempreadmintemp And Tempreadmaxtemp) And Lightreadminlight And (Humreadminhum And Hum- readmaxhum))	”Normal temperature” ”Normal light, lamp off” ”Normal humidity”
2	((Tempreadmintemp And Tempreadmaxtemp) And Lightreadminlight And Humreadminhum)	”Normal temperature” ”Normal light, lamp off” ”Low humidity, humidifier on”
3	((Tempreadmintemp And Tempreadmaxtemp) And Lightreadminlight And Humreadmaxhum)	”Normal temperature” ”Normal light, lamp off” ”High humidity, dehumidi- fier on”
4	((Tempreadmintemp And Tempreadmaxtemp) And Lightreadminlight And (Humreadminhum And Hum- readmaxhum))	”Normal temperature” ”Low light, lamp on” ”Normal humidity”
5	((Tempreadmintemp And Tempreadmaxtemp) And Lightreadminlight And Humreadminhum)	”Normal temperature” ”Low light, lamp on” ”Low humidity, humidifier on”
6	((Tempreadmintemp And Tempreadmaxtemp) And Lightreadminlight And Humreadmaxhum)	”Normal temperature” ”Low light, lamp on” ”High humidity, dehumid- ifier on”
7	(Tempreadmintemp And Lightreadminlight And (Humreadminhum And Humreadmaxhum))	”Low temperature, heater on” ”Nor- mal light, lamp off” ”Normal humid- ity”
8	(Tempreadmintemp And Lightreadminlight And Humreadminhum)	”Low temperature, heater on” ”Nor- mal light, lamp off” ”Low humidity, humidifier on”
9	(Tempreadmintemp And Lightreadminlight And Humreadmaxhum)	”Low temperature, heater on” ”Nor- mal light, lamp off” ”High humidity, dehumidifier on”
10	(Tempreadmintemp And Lightreadminlight And (Humreadminhum And Humreadmaxhum))	”Low temperature, heater on” ”Low light, lamp on” ”Normal humidity”
11	(Tempreadmintemp And Lightreadminlight And Humreadminhum)	”Low temperature, heater on” ”Low light, lamp on” ”Low humidity, hu- midifier on”
12	(Tempreadmintemp And Lightreadminlight And Humreadmaxhum)	”Low temperature, heater on” ”Low light, lamp on” ”High humidity, de- humidifier on”
13	(Tempreadmaxtemp And Lightreadminlight And (Humreadminhum And Humreadmaxhum))	”high temperature, fan on” ”Normal light, lamp off” ”Normal humidity”
14	(Tempreadmaxtemp And Lightreadminlight And Humreadminhum)	”High temperature, fan on” ”Normal light, lamp off” ”Low humidity, humid- ifier on”
15	(Tempreadmaxtemp And Lightreadminlight And Humreadmaxhum)	”High temperature, fan on” ”Normal light, lamp off” ”High humidity, dehu- midifier on”
16	(Tempreadmaxtemp And Lightreadminlight And (Humreadminhum And Humreadmaxhum))	”High temperature, fan on” ”Low light, lamp on” ”Normal humidity”
17	(Tempreadmaxtemp And Lightreadminlight And Humreadminhum)	”High temperature, fan on” ”Low light, lamp on” ”Low humidity, hu- midifier on”
18	(Tempreadmaxtemp And Lightreadminlight And Humreadmaxhum)	”High temperature, fan on” ”Low light, lamp on” ”High humidity, de- humidifier on”

Table 2
The Confusion Matrix and Horticulture Expert’s Suggestion.

”Temperature” Level	”Light” Intensity	”Humidity” Level	Class Names
4	0	0	”Temperature” Level
2	6	0	”Light” Intensity
0	0	6	”Humidity” Level

Confusion matrices offer a viable alternative to validation when measurements are discrete [33]. Hence, the performance of the prototype system is calculated using the confusion matrix presented in Table 2.

Table 2 shows the confusion matrix for the three (3) class classifier (Temperature, Light and Humidity). The entries in the confusion matrix have the following meaning in the context of this research. The first column shows that 6 flower cases are classified as” Temperature” level out of which 4 flower cases are correctly classified and 2 flower cases are incorrectly classified.

The second column shows the entire 6 flower cases are correctly classified as “Light” intensity flower cases. The third column shows, from the 6 “Humidity” level flower cases, all 6 flower cases are correctly classified as “Humidity” level. Accordingly, the following judgment was reached by the prototype system against the 18 test cases listed in Table 1 formulated by the horticulture experts.

In general, from 18 flower cases, 16 (88.89%) flower cases are classi- fied “correctly” and 2(11.11%) flower cases are classified “incorrectly”. In other words, our prototype system achieves a remarkable 88.89% accuracy. This highlights that much better environment monitoring can be applied to Ethiopian greenhouse industries with the help of an ACMS. The accuracy of the confusion matrix result was proofed using the parameters precision, re- call and F-measure. According to the TP Rate shown in Table 3 below, both ”Humidity” and ”Light” score the highest TP Rate with 100% climate condi- tion classified correctly followed by the ”Temperature” with 66.67% climate condition classified correctly.

Table 3
Comprehensive Accuracy of the Prototype.

TP Rate	FP Rate	Precision	Recall	F- Measure	Class Name
0.6667	0.26669	0.6667	0.6667	0.6667	"Temperature" Level
1	0	1	1	1	"Light" Intensity
1	0	1	1	1	"Humidity" Level
0.8889	0.08889	0.8889	0.8889	0.8889	Weighted Average

Table 4
Comparison of Automated PC-based Controller, and Timing Devices and ON/OFF.

No	Criteria	Technology PC-based Controller	Timing Devices and ON/OFF Controller
1	Simplicity	80%	70%
2	Efficiency in time	85%	71%
3	Accuracy Accessibility	78%	75%
4	Importance to the in-	90%	70%
5	dustry	90%	80%
Total Average		84.6%	73.2%

However, taking only the TP Rate for measuring the performance of the prototype's suggestion can be confusing. Instead, we should take the commonly used measuring parameters for measuring the performance of any classifier such as weighted average of precision and recall. Thus, the weighted average precision in Table 3 above shows 88.89% (which is the performance registered by the prototype's suggestion) of the predicted positive flower cases were correct. Similarly, the weighted average recall also shows 88.89% of the positive flower cases are among all cases that belong to the relevant subset. Therefore, the performance result obtained from the Confusion Matrix is "accurate and acceptable".

5.2. User Acceptance Analysis

A questionnaire with a 5-point Likert scale is employed as a data collection instrument from the end users/growers. We built the questionnaire based on the representational information quality dimensions of concise representa- tion, consistency, ease of understanding, and interpret-ability [34]. Following the ISO 9126 standards [35], we have selected the suitability criteria that incorporate simplicity, efficiency, accuracy, accessibility and importance of the technology to the greenhouse industry as shown in Table 4 below.

As shown in Table 4 below, the total average performance of both tech- nologies according to the evaluation results is 84.6% (ACMS) and 73.2% (Timing Devices and ON/OFF Controllers). In this research, the perfor- mance has significantly improved by 11.4% throught the integration of an ACMS into the greenhouse industry at 5% statistical significance level. This is because most Timing Devices and ON/OFF Controllers are prone to fail- ure due to human error of timing and device difficulty. For that reason, a much better environment monitoring is applied by integrating the Climate Monitoring System into greenhouse industries.

6. Conclusion

In this research, we aim to monitor the three most important parameters that play a great role in plant's growth. Thus, we developed an automatic, user-friendly and inexpensive prototype controller system called ACMS. The controller we applied is a Two-Position or ON/OFF Controller that contin- uously checks the environmental conditions and activates the corresponding output device to overcome the deviations from the desired values. The sen- sors detect their respective environmental conditions and will be an input to the ACMS through the PCL-818L interfacing card.

The ACMS sets the values according to the PHP program written, which was in turn provided to the digital output relay board. Having these digi- tal values, the relay board switches (ON/OFF) the devices to be controlled whose appropriate climate conditions were out of the desired range. As per our findings, most of Timing Devices and ON/OFF Controllers are prone to failure due to human error of timing, device difficulty and unavailability. So, we conclude that the ACMS is found to be better than the Timing Devices or ON/OFF Controller for maintaining optimal environmental climate con- ditions like humidity, light and temperature levels. In our case, there is a research improvement in monitoring of the three variables, humidity, light and temperature, comparing to previous monitoring habits (Timing Devices, ON/ OFF Controller and Human Monitoring). This entails that, with the aid of an automated computer technology, a much better environment mon- itoring can be applied to the greenhouse industries.

In keeping with the Design Science Research methodology, [36], we com- pared our ACMS performance (84.6%) with that of the Timing Devices and ON/OFF Controller's result (73.2%). As a result, the ACMS is found better than the Timing Devices and ON/OFF Controller. This shows there is a research improvement done by the researchers. Therefore, the implication of this research is that integrating an ACMS into greenhouse industries would be profitable and has competitive advantages in

Ethiopia. Finally, this re- search can be enhanced by adding more climate condition parameters like air flow and PH. So, our future research will concentrate on enhancing the performance by incorporating more climate condition parameters.

Declaration of Competing Interest

The authors declare no conflict of interest.

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