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ACHPA: A sensor based system for automatic environmental control in hydroponics

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Abstract

The trend towards tunnel farming and hydroponic systems is increasing owing to the climatic changes as well as the need to increase crop yield. Hydroponic is a technique of growing plants without soil. Tunnel farming and hydroponic system requires controlled environmental parameters like temperature, humidity and soil moisture for better production of crops. This paper presents an effective method, named, ACHPA (Automatically Controlled Hydro-Ponic Agriculture) scheme that monitor and controls environmental parameters using sensors and controller. ACHPA provides better environmental control over traditional manual monitoring and controlling, thus yield high-quality crops. Sensor based monitoring and control system regulates the temperature and humidity of the tunnel to yield better. For the sake of saving water, an efficient method of drip irrigation is implemented which delivers water directly to the plants rather than being sprayed on as in conventional farming method. The proposed system here is tested for controlled environment and observations recorded for crop analysis purpose. This makes an effective solution to growing highly efficient, good quality and disease free crop production.

Keywords: hydroponics; environmental control; sensors; controller; yield.

Practical Application: Automated hydroponics and tunnel farming.

1 Introduction

Agriculture has been one of the primary occupations of man since early civilization. Agriculture plays an important role in development of economy of nations and is considered as an essential part of human life cycle (Nalwade & Mote, 2017). In recent years, the world has faced a drastic change in climate resulting in increased environmental stresses like untimely floods, change in seasonal temperatures and wind dispatches. These changes have affected the field of agriculture with decreased production and crops quality. By 2050 world population is estimated to be 9 billions thereby increasing food necessity by 70% (Collado et al., 2018). One of the mechanisms used by the food industry to overcome this shortfall in the yield is the use of tunnel farming/hydroponics agriculture where environmental parameters like temperature, humidity and soil moisture are controlled. Controlled environment production involves more sophisticated growing techniques than unprotected cultivation in the field (Saha, 2017). The results from the Design Expert software showed height of the plants growing faster in hydroponic system as compared too traditional soil system (Gashgari et al., 2018).

Funding agencies like SMEDA and USAID have undertaken some experimental research on watermelon, apples, muskmelon, tomato and cucumber cultivation using tunnel farming. The results vary from country to country, but have shown expansion in growth in most of the cases. Food industries are undergoing technological transitions due to increase in worldwide population and unavailability of low cost fertile land. These transitions include tunnel farming for off-season as well as pre-season growth, vertical farming for big cities and home kitchen gardening to complete the individual needs.

Soil is the most accessible and widely used medium for crop production because it transfers supplements i.e. water efficiently and docks for development, but large use of pesticides in harvests brought poor fruitfulness in the soil. Hydroponics is the technique of growing plants without soil (Siddiqi, 2002). Roots submerged in hydroponic solution (Matos et al., 2015), with or without using dormant medium like Rockwool and coconut fiber (Mohanraj I, 2016), receives a balanced nutrition, essential for plant growth and development (Hirofumi Ibayash et al., 2016).

For many years, hydroponic system was manually controlled which resulted in low crop productivity due to inefficient method and improper control of environmental parameters. Then automated tunnel farming/hydroponics was introduced to overcome the problems occurred by manual control.

ACHPA controls environmental parameters i.e. temperature, humidity and soil moisture using sensors placed at convenient distances and a centralized controller to achieve a controlled environment for the production of crops. The operational ranges of the environmental parameters to be controlled are pre-fed in the controller. Environmental parameters received from the sensors are than compared with the pre-fed values for controlling action. Results strongly suggest using ACHPA controls environmental parameter in better way resulting in increased crop yield.

Environmental parameters i.e. temperature, humidity, soil moisture, and light directly influences the production of plants. These parameters are mostly responsible for the development of plants and play an important role in quality and productivity.

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Temperature influences plant development process like transpiration, respiration, and flowering. Humidity controls moisture loss of the plant because a decrease in transpiration rate is directly proportional to the amount of humidity in the air (Asolkar & Bhadade, 2015). Soil moisture is essential for the growth of plants because plants receive water and nutrients by roots and lose water by transpiration process. Plants manufacture glucose through the process of photosynthesis, which requires energy, which is directly captured from light (Asolkar & Bhadade, 2015).

In conventional tunnel farming method, the farmer has to go to farm regularly to check and measure environmental parameters (Kumar & Cho, 2014), which require an enormous amount of hard work and attention, some negligence, can also result in poor quality and low productivity (Asolkar & Bhadade, 2015). Automated controlled tunnel farming and hydroponic system help to overcome the problems occurred by manual control and traditional farming. Controlled environment agriculture (CEA) supplements crop production and quality by protecting the crops from pest, diseases and maintaining growing conditions (Niu & Masabni, 2018).

Hydroponics plants have various types of planting media such as Rockwell, sponge, coconut and other coconut powder (Sihombing et al., 2017), (Velazquez et al., 2013). The key benefits of hydroponic technology include water reusability and low plant damage due to controlled pesticide use (Mr & Kulkarni, 2017). Further drip irrigation technique supplies small water to the roots of plants, which ultimately save a lot of water (Rammurthy, 2010), (Singh & Bansal, 2011), (Aniket Hade & Sengupta, 2014). Water is supplied frequently, often daily, to maintain soil moisture condition with proper use of water resources (Shweta Bopshetty, 2017), (Sales et al., 2015). Drip irrigation system makes the proficient use of water because water is directly fed to the roots of plants with no or low losses (Agrawal & Singhal, 2015), (Hussain et al., 2013).

Due to the issues in manual hydroponics, automated controlled hydroponics has been discussed in many papers and remains an open field of research.

(Asolkar & Bhadade, 2015) gave an effective method of controlling the greenhouse and crop monitoring using GSM, proposing an effective method to replace traditional farming. (Nishimura et al., 2018) provided a high accuracy and low-cost sensor module to measure temperature and nutrition level. Only for a remote control area, which is difficult to establish. (Adhau et al., 2017) worked on designing a fully automated low cast hydroponic system in which a self-controlled automated system was developed to import real-time data using AVR microcontroller. According to him, the progress in hydroponics by only using on-off controller is sufficient, in this regard PID controller not required. (Dania et al., 2015) provided an Arduino-based nutrition feeding automation system for scaled nutrient film technique, aims to provide water and nutrients delivery automatically to the roots of plants. However, such direct water supply to the roots creates water loss problem, drip irrigation gives much better results to save water. (Burchi et al., 2018) designed a high technology greenhouse to manage a controlled environment in an efficient way for different crops. The system was equipped with sensors and monitoring system. However, the project was only for small scale and not tested for large scale. (Saraswathi et al., 2018) worked on automation of greenhouse hydroponic system and maintenance of PH and electric conductivity in the hydroponic system. This is also implemented only for the small scale.

Controller design is a major topic in automatic technologies. On off controller, PID or combinations of these terms (P, PI, and PD) are most commonly used in industrial position control, robotics and motor drive (Jahanshahi, 2015), (Ponce et al., 2015), (Reyes & Rosado, 2005), (Sondhi & Hote, 2014), (Jingzhuo et al., 2014), (Can & Ozguven, 2017). PID controllers (Ziegler & Nichols, 1940), (Haglund, 1988, 1995) are widely used in industrial control systems because PID controllers have the capacity to eliminate the steady-state error of signals (Matos, 2002). PID controller supplies smooth control action, numeric output and makes the system stable (Adhau et al., 2017).

A thorough review of the above work shows there are only a few studies concerning monitoring and controlling of tunnel farming and hydroponic unit. Above discussion described implementation of the control unit in a remote area only, expensive method of controlling using PID controller implemented only in a small scale and water losses using simple water supply to the crops. The current paper considers these problems and proposes an efficient approach to monitoring and controlling mechanism for completely automated hydroponic system.

This paper comprises of following sections: Section 2 explains the materials and methodology of the proposed system. Section 3 explains the analysis and experimental results. Section 4 summarizes the results and conclusion generated by the proposed system.

2 Materials and methods

This section explains the methods and processes used in system development as shown in Figure 1. It completes in four stages, stage 1: data analysis, stage 2: controller command, stage 3: system implementation and stage 4: rechecking of previously stored data

The first stage in system development is the identification of the system requirements. At this stage, sensor data is analyzed namely DHT11 (temperature and humidity sensor). Then these values are sent to the controller for processing.

In the second stage, the controller reads data sent by sensors and commands to the actuator to maintain a controlled climate for the crops. In stage 3, to overcome the effects of high temperature, proper ventilation is required so the fans are turned

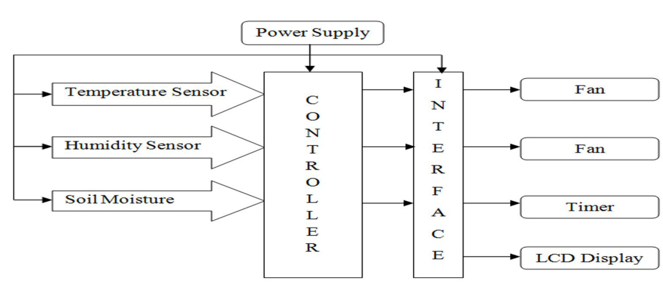

Figure 1. Block Diagram.

ON and after regulating the temperature; they are commanded to be turned OFF. In addition, for maintain the adequate water moisture for the roots; water pumps of drip irrigation system are regulated upon readings received from moisture sensors.

Data collected by the sensors is stored to evaluate growth with regulated climate conditions. It will allow the stakeholder to continuously monitor the cultivation system. A basic chart of the process is shown in Figure 2 below.

To better understand the working of the system, assume that the fans are initially off and the temperature of the tunnel increases than the preset threshold value i.e. more than 40 °C. The controller after checking the present state of the fans (F=0) will switch on the fans changing the status as F=1. The controller will recheck the temperature value after every 2 minutes. If F=1 and temperature is greater than 37 °C, the controller will do nothing and the fan will remain ON. If F=1 and the temperature becomes equal to or less than 37 °C, the controller will turn off the fan making F=0 in the software variable F. The procedure gives a range of 3 °C for ON-OFF control. A similar procedure is adopted for humidity control with variable H in the software. In case temperature and humidity variables are competing, temperature is given priority over humidity since temperature plays more vital role in crop yield than humidity. Moisture is controlled using a timer. As soon as the moisture is sensed below 96%, pumps start supplying water for three minutes. LCD display attached shows all current values of temperature, humidity and soil moisture.

3 Results and discussion

In this paper, a system is designed to check and compare the difference of the manually controlled tunnel farm with automatically controlled tunnel farm for the regulated and varied values of temperature and humidity. Monitoring values of manually controlled farm are taken after every thirty minutes and automatically controlled farm values are programmed to be read after every two minutes. Values of temperature and humidity have been taken 8 hours per day (day light), at different atmospheric temperatures on different days. The results are simulated using MATLAB. Threshold values of temperature and humidity are described below.

The threshold value of temperature = 37 to 40 °C

The threshold value of humidity = 55 to 60%

Day 1

Table 1 shows the data of day 1 with temperature Range of 33 to 43 °C and behavior graph is shown in Figure 3 and Figure 4.

Day 2

Table 2 shows the data of day 2 with temperature Range of 30 to 35 °C and behavior graph is shown in Figure 5 and Figure 6.

Day 3

Table 3 shows the data of day 3 with temperature Range of 34 to 42 °C and behavior graph is shown in Figure 7 and Figure 8.

Day 4

Table 4 shows the data of day 4 with temperature Range of 35 to 45 °C and behavior graph is shown in Figure 9 and Figure 10.

Table 1. Average of Field Observation (Day 1).

Day 1				
Parameters	Min	Max	Median	SD
Temperature (°C)	33	43	38	4.5
Humidity (%)	55	63	58.5	3.53
Soil Moisture (%)	95	100	97.5	2.06
Time (hr.)	0	8	4	3.53
Distance (ft.)	0	150	75	74.5

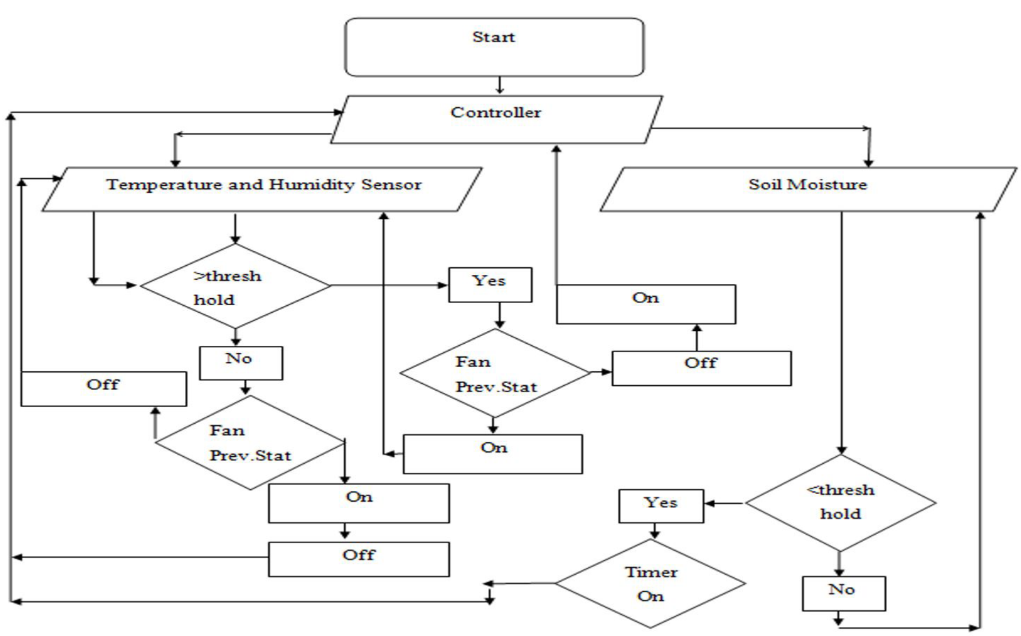

Figure 2. Flow Chart for System Design Process.

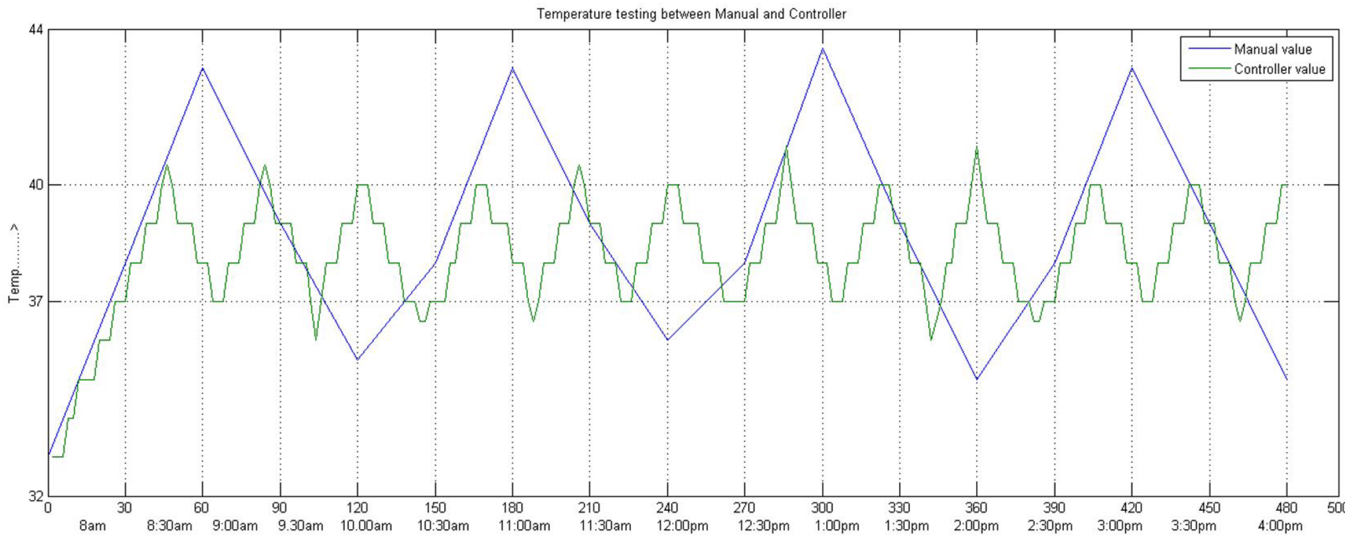

Figure 3. Time vs. Temperature (Day 1).

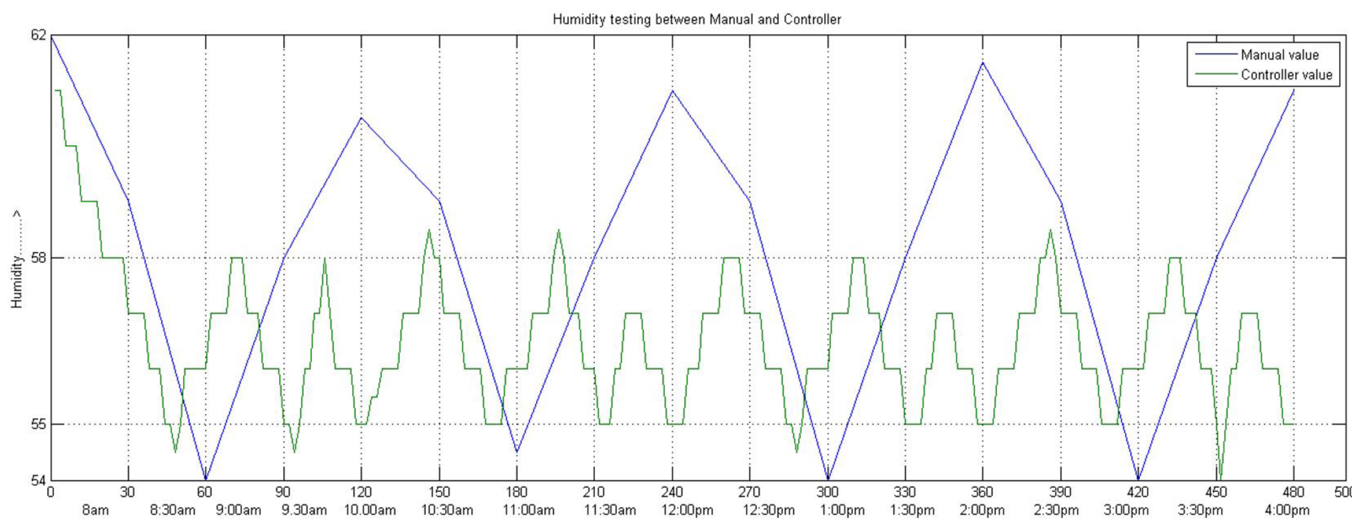

Figure 4. Time vs. Humidity (Day 1).

Table 2. Average of Field Observation (Day 2).

Day 2				
Parameters	Min	Max	Median	SD
Temperature (°C)	30	35	32.5	2.06
Humidity (%)	55	63	58.5	3.53
Soil Moisture (%)	96	100	98	1.58
Time (hr.)	0	8	4	3.53
Distance (ft.)	0	150	75	74.5

Table 3. Average of Field Observation (Day 3).

Day 3				
Parameters	Min	Max	Median	SD
Temperature (°C)	34	42	38	3.53
Humidity (%)	53	63	57.5	4.52
Soil Moisture (%)	95	100	97.5	2.06
Time (hr.)	0	8	4	3.53
Distance (ft.)	0	150	75	74.5

Day 5

Table 5 shows the data of day 5 with temperature Range of 33 to 43 °C and behavior graph is shown in Figure 11 and Figure 12.

Day 6

Table 6 shows the data of day 6 with temperature Range of 33 to 43 °C and behavior graph is shown in Figure 13 and Figure 14.

In the graphs, there are different values of temperature and humidity at different days and time. After the comparison between manual and controller values, it is concluded that in manual control, values of environmental parameters varies largely and is summarized in Table 7. This variation in temperature or humidity in manual control creates a problem to maintain the required condition of environment for crops thereby affecting the quality and yield.

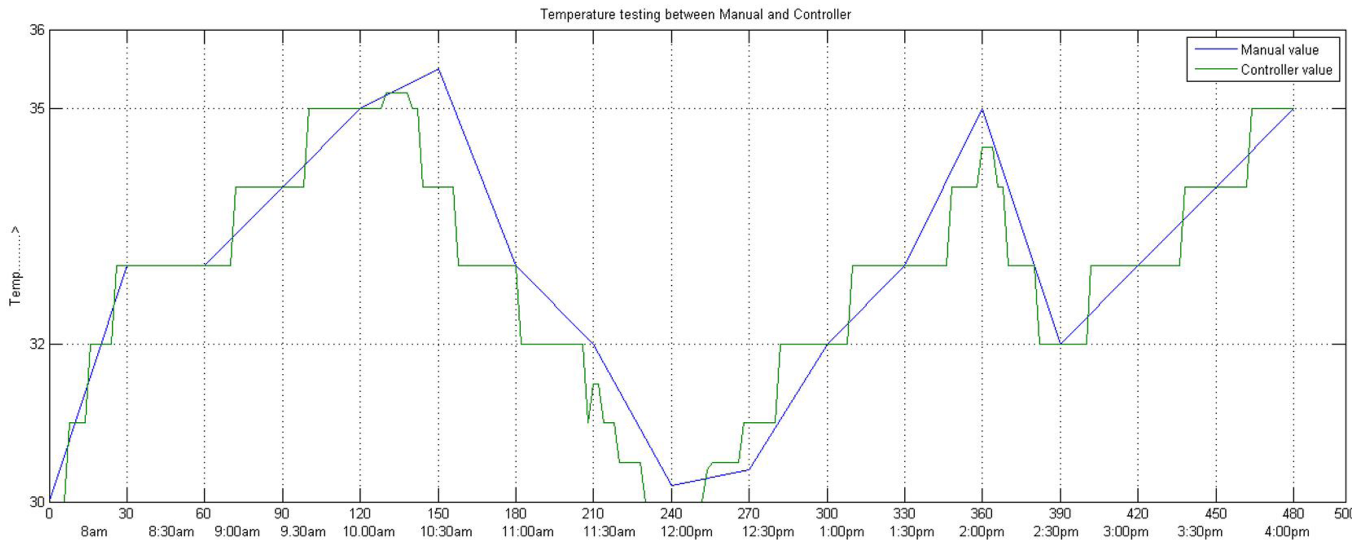

Figure 5. Time vs. Temperature (Day 2).

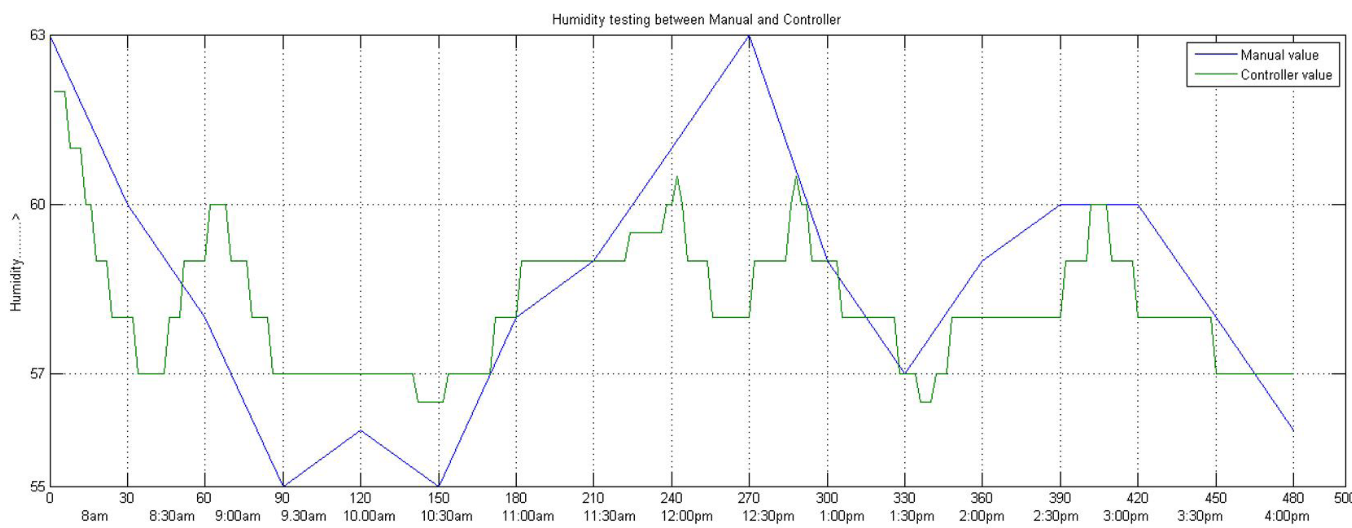

Figure 6. Time vs. Humidity (Day 2).

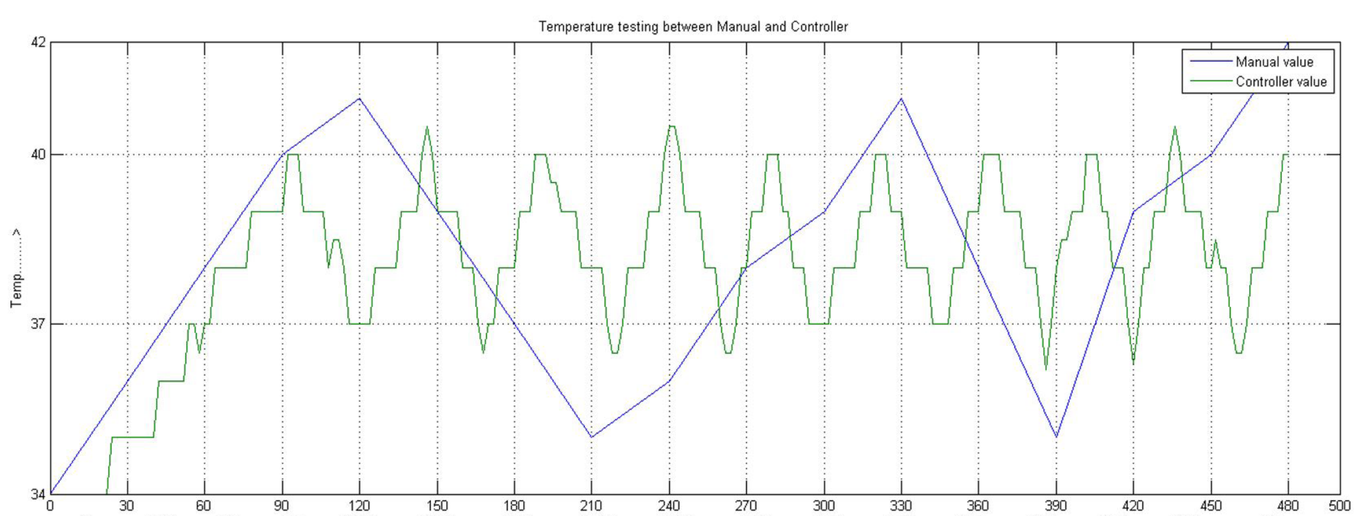

Figure 7. Time vs. Temperature (Day 3).

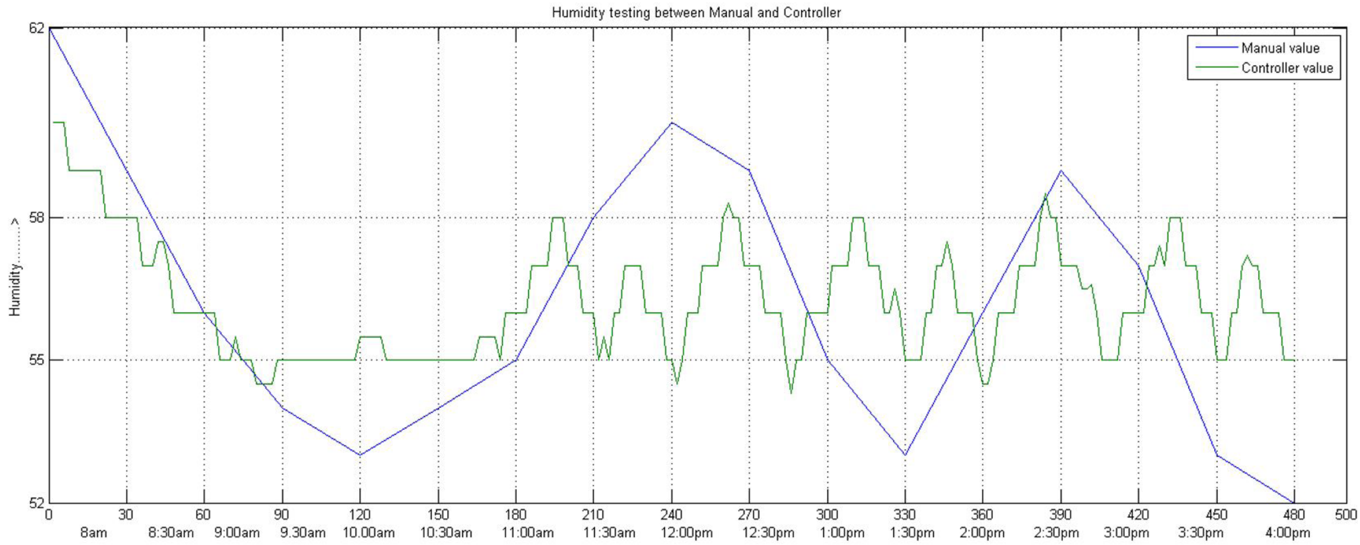

Figure 8. Time vs. Humidity (Day 3).

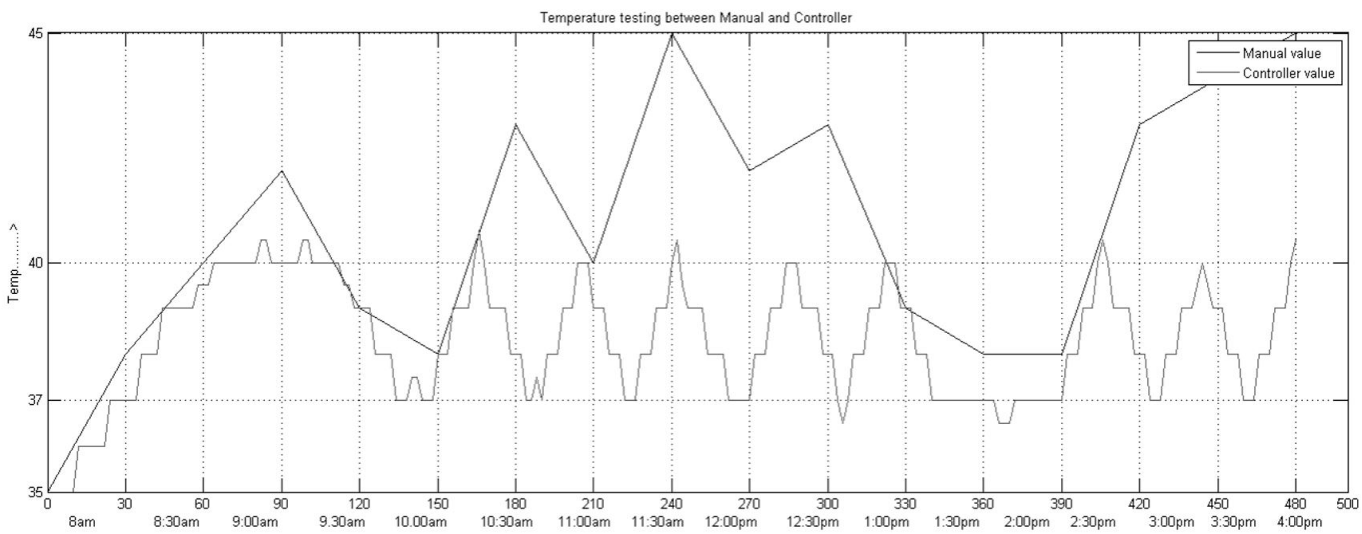

Figure 9. Time vs. Temperature (Day 4).

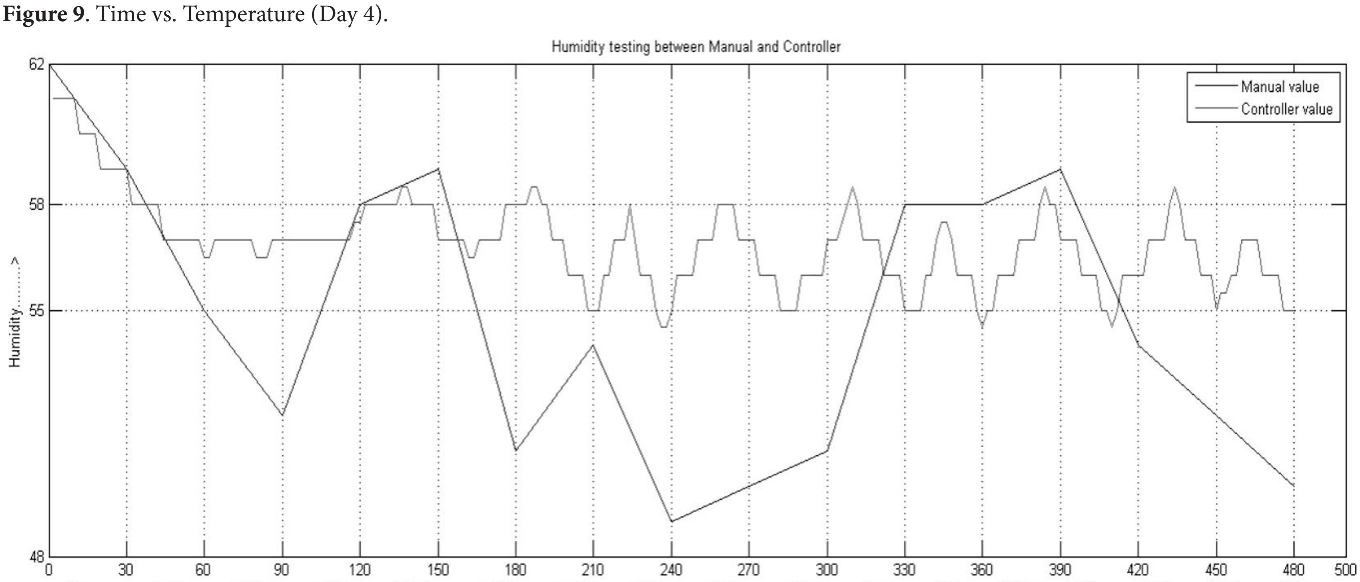

Figure 10. Time vs. Humidity (Day 4).

Table 4. Average of Field Observation (Day 4).

Day 4				
Parameters	Min	Max	Median	SD
Temperature (°C)	35	45	40	5.02
Humidity (%)	50	61	55.5	5.02
Soil Moisture (%)	94	100	97	2.38
Time (hr.)	0	8	4	3.53
Distance (ft.)	0	150	75	74.5

Table 5. Average of Field Observation (Day 5).

Day 5				
Parameters	Min	Max	Median	SD
Temperature (°C)	33	43	38	4.5
Humidity (%)	56	63	59	3.53
Soil Moisture (%)	95	99	97	2.06
Time (hr.)	0	8	4	3.53
Distance (ft.)	0	150	75	74.5

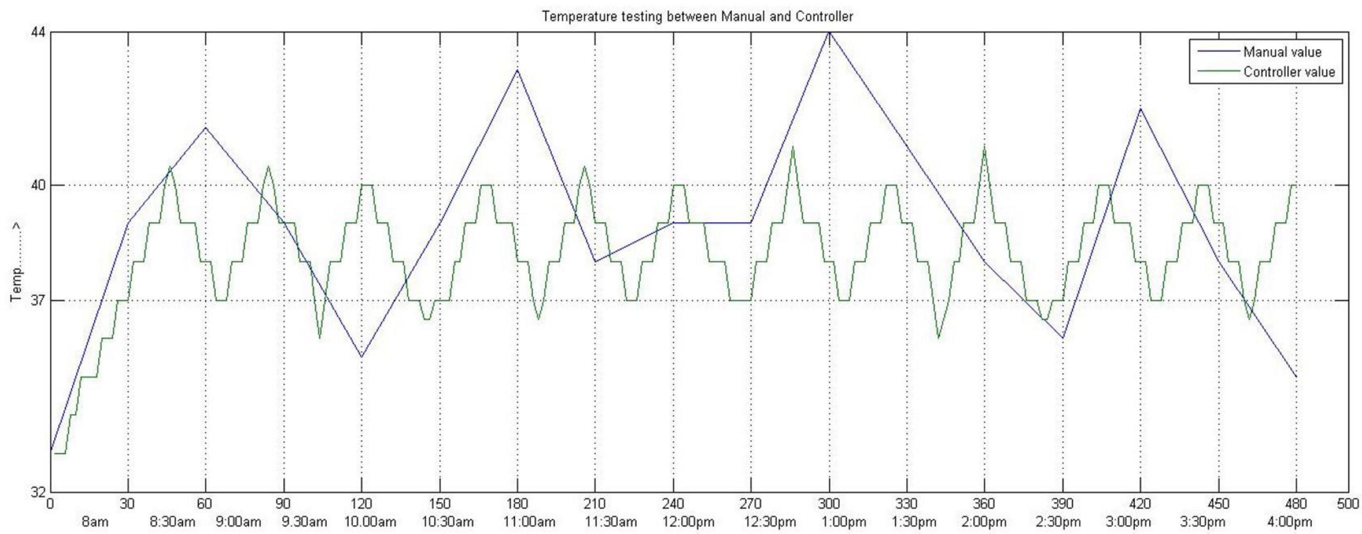

Figure 11. Time vs. Temperature (Day 5).

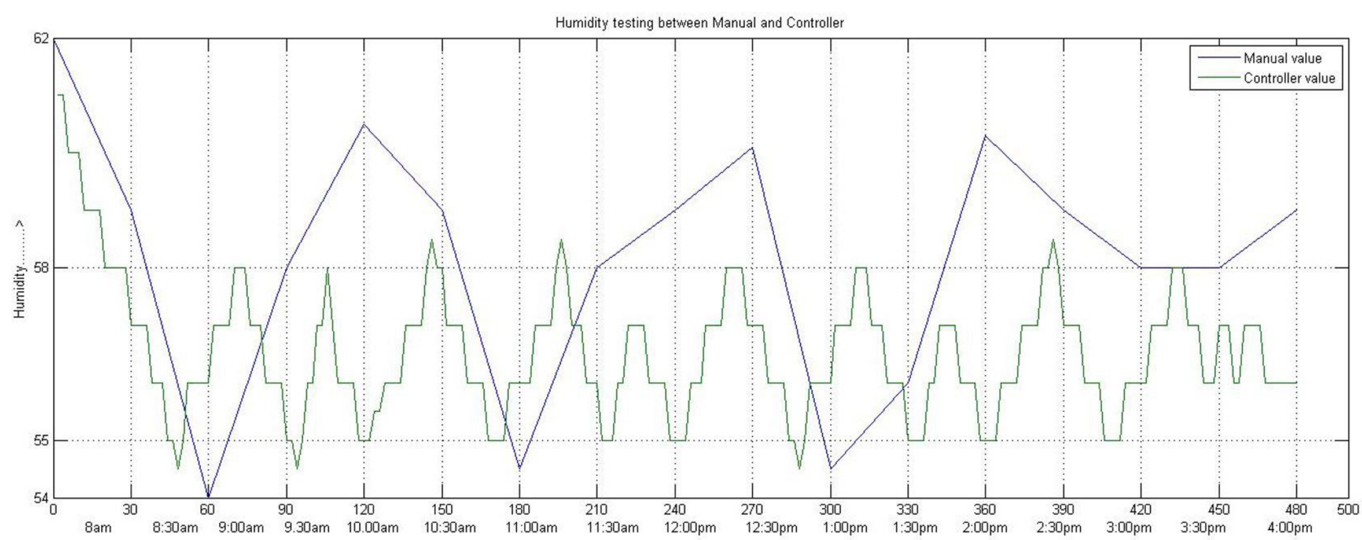

Figure 12. Time vs. Humidity (Day 5).

Table 8 summarizes the percentage time during which the environmental parameters have exceeded threshold values. It is evident that ACHPA significantly reduced the percentage variation time depicting better control. ACHPA improved 22% of the total sampled variation time for temperature giving a 5X better control on temperature. Humidity variation is improved by 30% giving 6X better humidity control as compared to manual control. Overshoot in the temperature and humidity reduced from 7.5% to 1% giving 7X better control. The proposed system checks the values of parameters through sensors and regulates the actuators to maintain the threshold range, providing excellent control over environmental parameters.

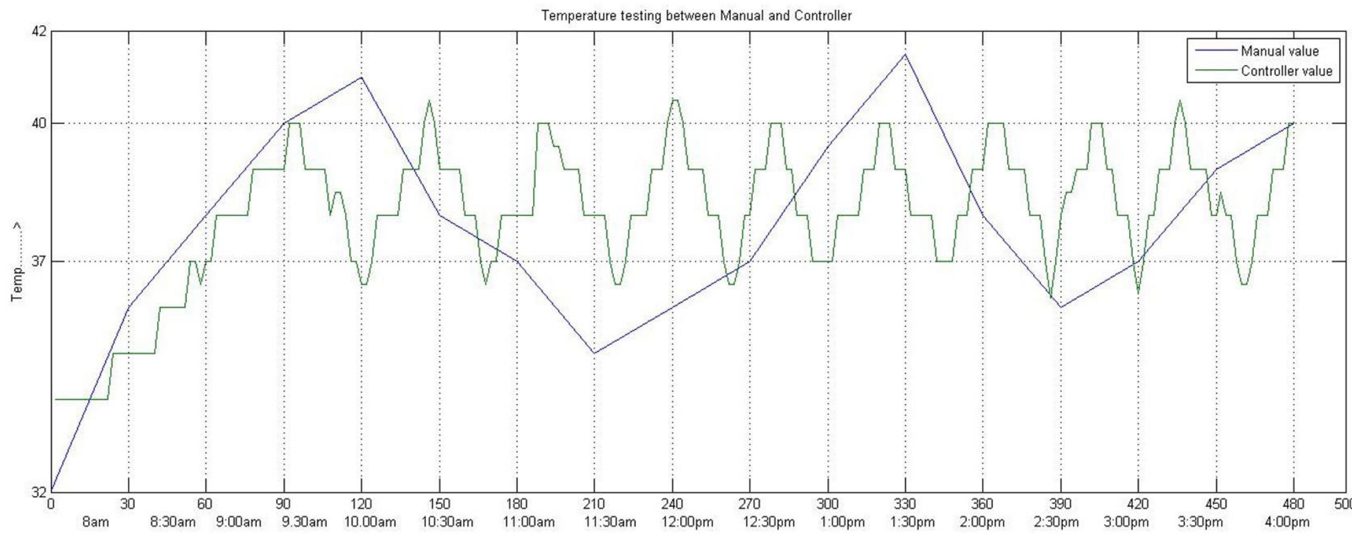

Figure 13. Time vs. Temperature (Day 6).

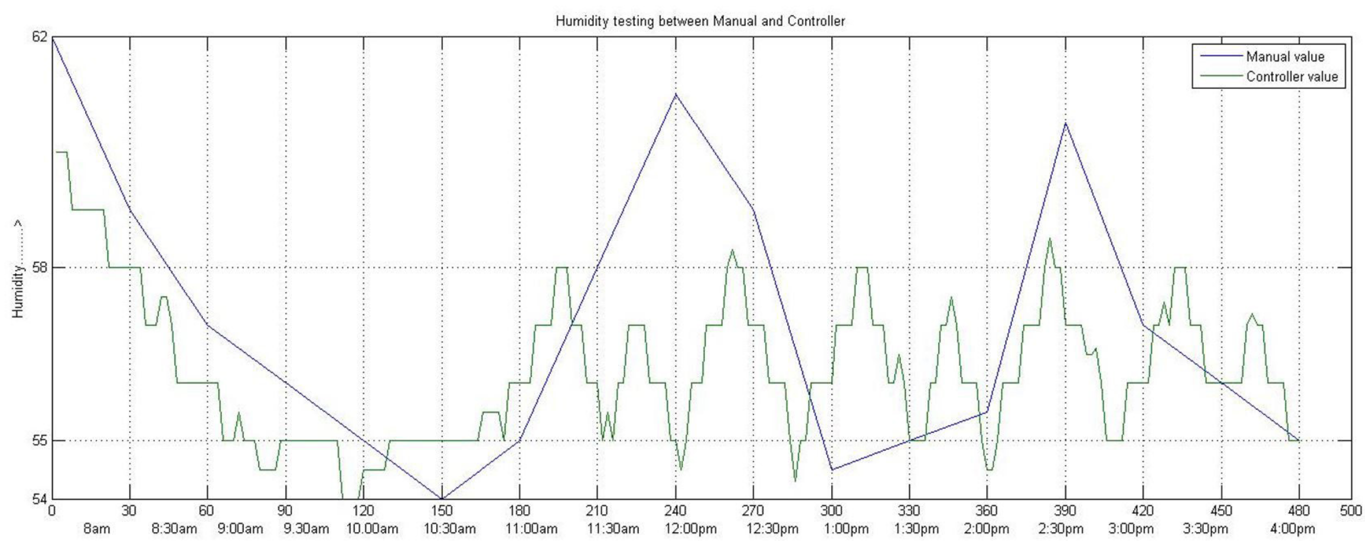

Figure 14. Time vs. Humidity (Day 6).

Table 6. Average of Field Observation (Day 6).

Day 6				
Parameters	Min	Max	Median	SD
Temperature (°C)	32	41	37	4.3
Humidity (%)	56	61	58	3.42
Soil Moisture (%)	95	100	97.5	2.06
Time (hr.)	0	8	4	3.53
Distance (ft.)	0	150	75	74.5

Table 7. Comparision between manual and controller values.

Days/ Parameters	Manual Values						Controller Values					
	Temp (°C)		Humidity (%)		Soil Moisture (%)		Temp (°C)		Humidity (%)		Soil Moisture (%)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Day 1	33	43	55	63	75	86	37	40	55	58	95	100
Day 2	30	35	55	63	51	78	30	35	55	58	95	100
Day 3	34	42	53	62	67	81	37	40	55	58	95	100
Day 4	35	40	50	61	59	83	37	40	55	58	95	100
Day 5	33	43	55	63	57	81	37	40	55	58	95	100
Day 6	32	41	56	61	64	89	37	40	55	58	95	100

Table 8. Comparitive results of manual and automatic controlled tunnel farm.

Parameter	Manual Control	Automatic Control	Percentage Difference
Temperature variation	27.5%	5.41%	22%
Humidity variation	36.2%	5.62%	30%
Overshoot	7.5%	1%	6.5%

4 Conclusion

The automatic controlled system based on sensor and actuator technology is proposed, which is designed and enforced to realize modern agriculture system. Sensor module system with a controller is developed for a hydroponic system, to measure and control temperature, humidity and soil moisture.

After complete analysis of the manually and automatically controlled farm, it is concluded that the temperature variation was recorded to be 27.5% and 5.4% respectively. Hence a 5X better control is possible using ACHPA. The humidity variation is 36.2% and 5.6% for manually and automatically controlled farm respectively resulting in 6X better control with ACHPA. The overshoot in the values are 7.5% and 1% in manually and automatically controlled farm respectively giving 7X better control with ACHPA.

The sensor based module system is tested and the performance of the system was approved by the experimental results. Testing, analysis and experimental results explore that it is a good solution to overcome problems occurred by manual control. In addition, it examines a reliable solution to maintain proper climate condition for environmental parameters, which results in an increase of yield, quality, and a disease free crop production.

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