Pertanika J. Sci. & Technol. 21 (2): 365 - 374 (2013)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Development of an Automation and Control Design System for Lowland Tropical Greenhouses

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ABSTRACT

Vapour pressure deficit (VPD) analysis introduces an approach to develop a better basis for the control of the environment of lowland greenhouses in Malaysia. The study of vapour pressure deficit (VPD) is to show air moisture conditions for plant production while taking into account different temperature levels. The purpose of this project is to develop a real-time automatic temperature and relative humidity control system in the lowland tropical greenhouse using a PIC16f876A microcontroller. The controller will then be used to monitor the temperature, relative humidity and VPD in the planting of Chili Kulai (*Titisan 15*). The fertigation system was introduced to the greenhouse to fertilize and irrigate the plant as well as to provide moisture to the environment. A swamp cooler was used to bring down the temperature and increase moisture content in the greenhouse. Ventilators were installed to remove the heat in the greenhouse. The study was carried out in an experimental greenhouse located at the Institute of Advanced Technology, Universiti Putra Malaysia (UPM).

*Keywords:*Microcontroller, Gantry System, automation system, fertigation system, plant growth parameter

INTRODUCTION

Agriculture is one of the most important industries all over the world. Even in the holy Quran, 83 verses were revealed concerning agriculture and this can be seen as a form of worship to the creator Almighty, Allah. As reported in the writing of a famous Islamic scholar, Imam Nawawi in *Kitab Sahih*, the best work or effort for human beings is agriculture.

In Malaysia rapid population increase has led to a high demand for food in terms of quantity and quality, a trend that has attracted the government's attention (Wan Ishak, 2007). In order to enhance crop production in the country, several enhancements and techniques have been conducted on the fabrication of

Article history:
Received: 17 January 2011
Accepted: 14 November 2011

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ISSN: 0128-7680

agricultural machines (Wan Ishak *et al.,* 2008a, 2008b). However, crop cultivation in lowland tropical areas has not reached optimal crop production as crops are still subjected to various stresses such as heavy rainfall, insects, exploration and extreme solar radiation. These stresses can be prohibited if the crops are cultivated in greenhouses. The initial objective of greenhouse environment control is to create ideal climate conditions for plant growth (Nelson, 2003). The Malaysian lowland environment has high relative humidity (RH) of more than 80% which limits the utilisation of various methods of greenhouse cooling, especially during hot hours of the day. Plants from tropical climates need higher humidity. Both temperature and relative humidity are interrelated. When the temperature is high, plants transpire heavily and when it is low, they tend to reduce transpiration, which reduces growths. To moderate the transpiration rate of the plant, the control system of greenhouses should provide higher humidity when the temperature is high especially to reduce transpiration (Ramin & Wan Ishak, 2007).

The application of a mechanisation and automation control system in greenhouses has generated the most suitable conditions and environment based on the features and growth requirement of each crop (Wan Ishak *et al.*, 2004). For vegetables to grow competently in a greenhouse, continuous control of temperature and relative humidity at exact optimum levels are required. In addition to this, other parameters have to be controlled in the greenhouse include CO_2 concentration, light and nutrient composition. Generally, the values of relative humidity and temperature measured in a greenhouse are defined in terms of vapour pressure deficit (VPD), a term referring to the difference between saturated and actual vapour pressure. VPD analysis introduces an approach to develop a better basis for environment control for lowland greenhouses in Malaysia. In short, VPD functions as an excellent indicator of the condensation potential and provides a valuable way to measure climate conditions in greenhouses (Prenger & Ling, 2007). A VPD calculator given by Autogrow Systems Ltd. (2011) was used to calculate VPD based on data captured in this research.

In order to incorporate greater use of computer applications in agriculture, an automatic temperature and relative humidity control system with a closed-loop ON/OFF control algorithm was developed using Programmable Interface Controller (PIC) in this research. Chili or hot pepper was chosen and planted in this project as chili is one of the most important economically-grown vegetables in the lowland and is probably second only to tomato. This is evident from the Malaysian cuisine which uses the chili in a wide range of dishes. Chili is also the main ingredient in the processing industry, which churns out huge amounts of chili products such as chili sauce, dried pepper and pickled pepper.

The objectives of this experiment were: (i) to develop an automation and control system for greenhouses; (ii) to develop a data acquisition system to model the growth of the chili plant in a greenhouse; (iii) to be able to monitor the growth of the chili plant; and (iv) to evaluate the performance of the developed system in terms of water requirement, temperature and humidity control in the greenhouse. Environment control in a greenhouse is quite challenging due to the nature of the variables which form a complicated dynamic system, influenced by changes of several internal and external factors.

METHODOLOGY

The study was conducted in a lowland tropical greenhouse of dimensions 10m x 4m. The greenhouse was fully covered with polyethylene film at Institut Teknologi Maju (ITMA) UPM as shown in Fig.1. To validate system performance, a number of experiments were carried out in February 2010. In this project, 27 Chili Kulai (*Titisan 15*) in vegetative stage were planted using the fertigation system in polybags in the greenhouse and 3 Chili Kulai were planted in an open field beside the greenhouse as a control experiment. The plants were placed in an area of dimensions 6m x 3m with a total of 27 polybags with 9 polybags for each row in the greenhouse. Fig.2 shows the *chilli kulai* species that was chosen for this project.

Plants were grown in an automatic control system in the lowland tropical greenhouse with a mechanically ventilated and cooling system using a circulation swamp cooler, vent and fogger which provided control and coordination of temperature and relative humidity. The fertigation system was used to provide water and nutrient for the crops. The fertigation

Fig.1: The greenhouse structure used in this research

Fig.2: *Chilli kulai* (*Titisan 15*)

system allowed sufficient water and a nutrient solution to be supplied directly to the plant's root zone. Sufficient water and fertiliser were supplied to the crops automatically through a system using a daily timer. The temperature and relative humidity were recorded and saved in EEPROM every half an hour.

The data acquisition system for temperature and relative humidity was developed using a microcontroller and installed in the greenhouse at Institut Teknologi Maju (ITMA), UPM. Temperature and relative humidity were monitored along the planting process in order to maintain the environment at an optimal VPD. The system was monitored and validated with the calculated VPD set-points for *chili kulai* (*Titisan 15*). The ideal VPD was set at 0.85 kPa in this research since this value is the ideal value for most crops (Prenger & Ling, 2007).

Software Programming

The programme was compiled on aPIC16F876A chip and the PIC training kit was installed in the greenhouse for automatic control purposes during planting. The I/O pins of the training kit were connected to output actuators which were controlled by relays. After installing the system, planting was done. Sensory data were received by microcontroller during planting and stored in EEPROM memory. Finally, analysis of data was done using an online VPD calculator (Autogrow Systems Ltd, 2011).

The system as tested in a controlled operation. The flow chart of the programme is shown in Fig.3. One temperature and one relative humidity sensor were installed inside and outside the greenhouse. The ideal VPD value was set at 0.85 kPa in this research since this value is the optimum value for *chili kulai*. On the other hand, VPD with 0.85 kPa also represents RH=55% and T=17°C at the same time. Thus, RH=55% and T=17°C were used as temporary set-points in this project. The logic for this was that if RH were 55%, the system would proceed to the next command and would check the value of the temperature to see if it was in set-point. Fogging was automatically turned on when the system received a signal from the PIC I/O pin if the RH value was lower than 55%. The actuator continued in on-mode until there were no error signals sent to the input from the sensor. However, the PIC sent a signal to activate the fans if the RH were greater than 55% as wet conditions are extremely suitable for crop growing. The programme counter runs itself every minute. The overall performance of the system in maintaining the temperature and relative humidity around the set-point was observed to be satisfactory. The PIC controller was required to generate the appropriate control signal applied to the controlled system and the actuators in greenhouse. The feedback elements, temperature and relative humidity sensors were the components required to establish the functional relationship between the primary feedback signal and the controlled output. Fig.4 shows the PCWH C Compiler software and the PIC programmer used in this study.

Mini28PIC Training Kit

A 28-way PIC training kit was used in this project and the PIC16F876A was selected as the 'brain' of the system. This training kit consists of PIC16F876A chip, LCD module, LED, buzzer, serial EEPROM, +5V converter, temperature sensor (LM35), humidity sensor, RS232 interfacing module, motor driver and switch input. The reason for selecting this type of PIC

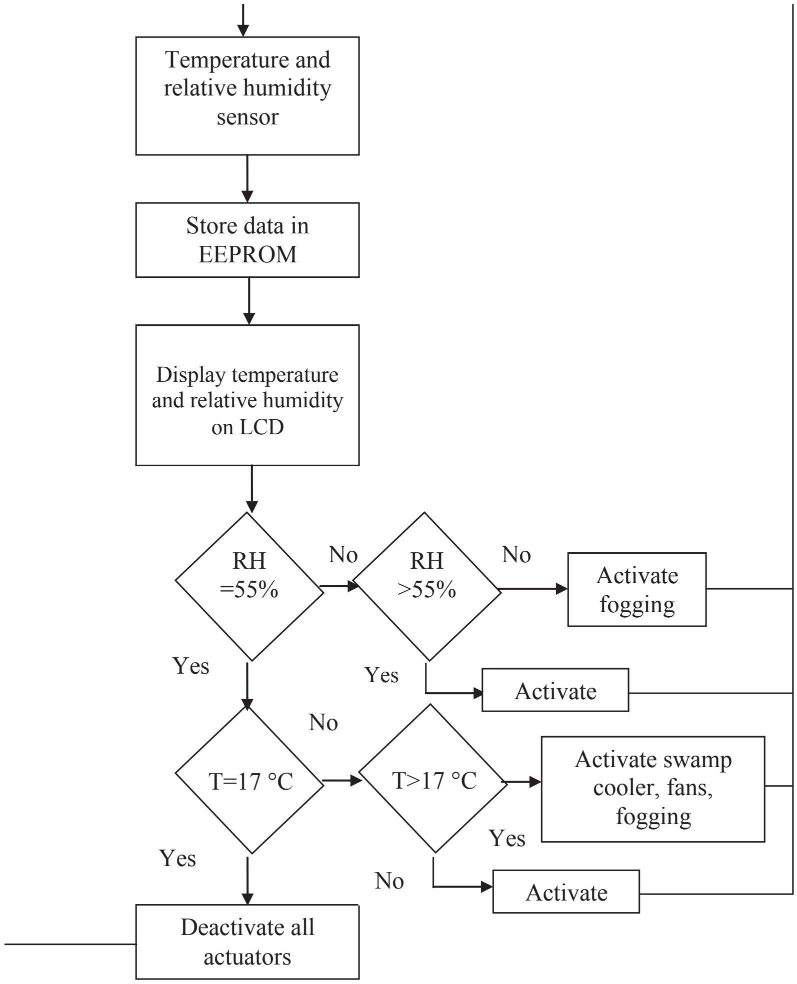

Fig.3: Flow chart of the programme used to control the system

Fig.4: The ‘PCWH C Compiler’ software (left) and the PIC programmer (right) used in this study

as the microcontroller in this research was because it is an efficient tool that is very suitable to develop a simple and small project. It was used to collect the real-time data which can be shown in computer interfacing.

In this project, data from temperature and relative humidity were sent to the PIC via the I/O pins as input for the controller. Pins a_0 and c_0 were used as temperature and relative humidity input signals respectively while the pin of PORT B was used as the output for LCD display on the training kit. Pins a_1, a_2 and a_3 of PORT C were used as the output to activate actuators in the greenhouse. Fig.5 shows the training kit and its components that were used in the research. The data from the temperature and humidity sensors were sent to PIC controller as the input signal and were converted to digital form through internal analog to the digital convertor (ADC) inside the controller. Output signals were sent to activate the actuators after running the programme.

Strip board

A strip board was developed and used to supply 5V to trigger relays in the controller box and regulate the DC adapter voltage from 12V to 5V. It consisted of an LM 7805, pin header, resistor and capacitor. LM35 is a simple but accurate 3-pin temperature sensor. It is included in the training kit to determine the temperature in the greenhouse at a certain time and period. Its temperature range is from 2°C to 100°C. This temperature range allows the sensor to detect the temperature value in the greenhouse where the temperature is different throughout the day. Fig.6 shows the circuit diagram of the strip board and the temperature sensor, LM35.

Graphical User Interface (GUI)

A Graphical User Interface (GUI) was developed by using Microsoft Visual Basic 2006 software. This GUI was developed to help the user to ensure that actuators are activated based on the temperature and relative humidity set-points.

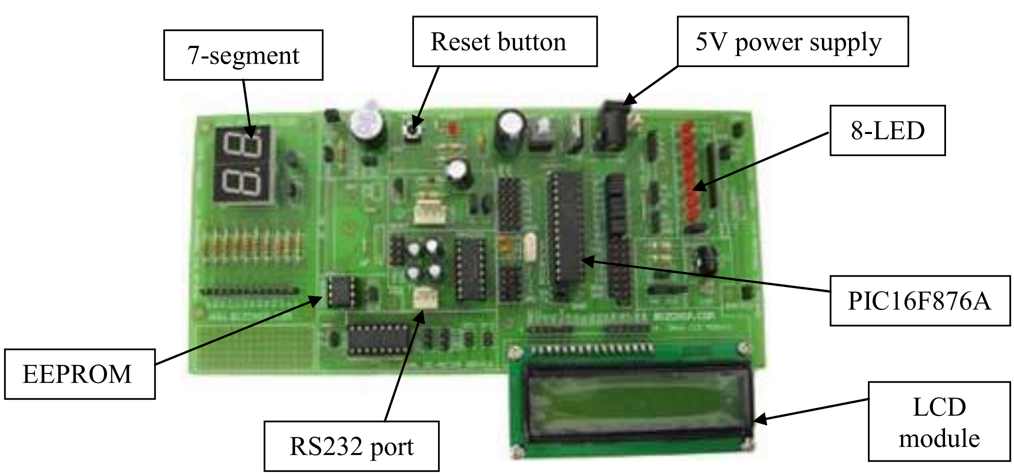

Fig.5: The PIC training kit and its components

This GUI showed the system check-list for the actuators according to the temperature and relative humidity. The user gets the optimum temperature, relative humidity and VPD values according to the type of plant cultivated. This GUI can be used for other crops in subsequent studies.

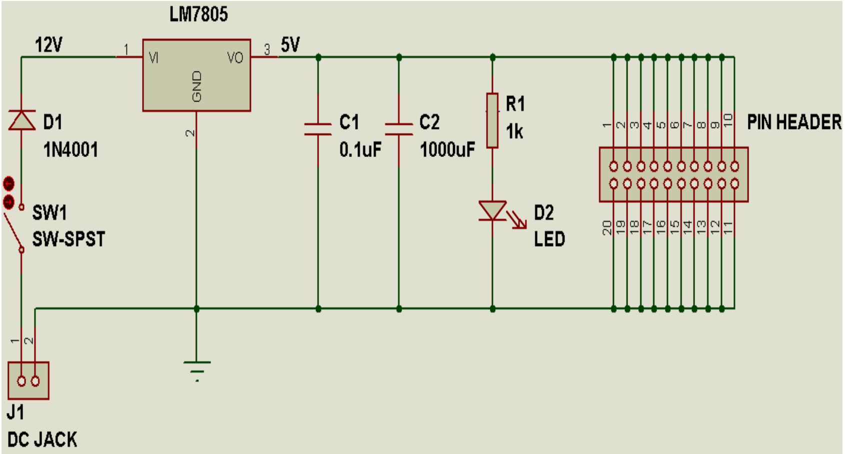

Fig.6: Layout of circuit diagram of strip board and temperature sensor, LM35

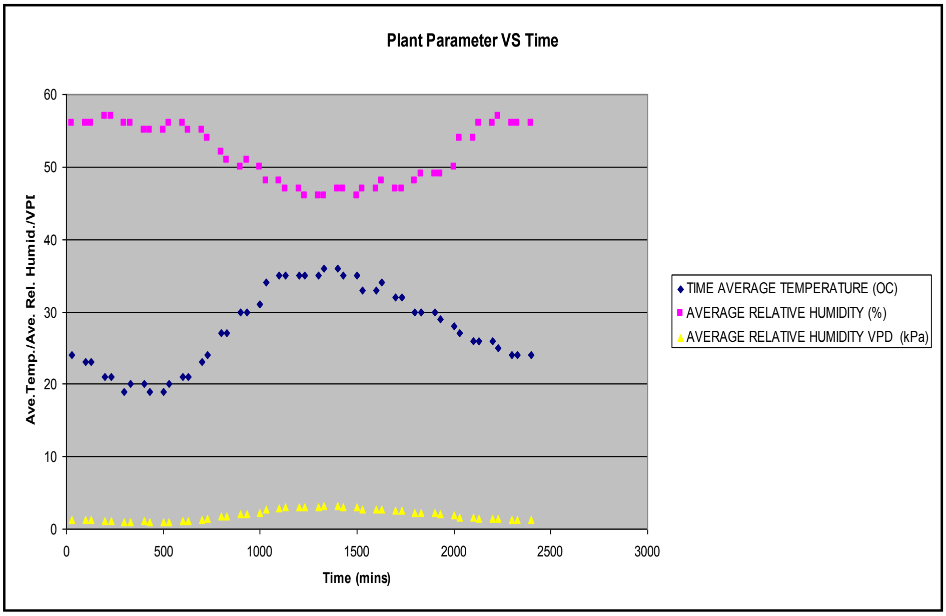

Fig.7: Readings for temperature, relative humidity and VPD inside the greenhouse

RESULTS AND DISCUSSION

The data related to temperature and relative humidity inside and outside the greenhouse were captured during the planting period. Part of the data is shown in Fig.7. A VPD calculator (Autogrow Systems Ltd, 2011) was used to calculate the VPD based on the data collected. Fig.8 shows the online VPD calculator interfacing.

At the start of the research, the plants experienced transplanting shock when they were transplanted into bigger polybags. However, after a few weeks of adaptation, plant growths were found to be healthy. There were no flowers and fruit obtained in the vegetative stage. However, in the flowering stage, the maximum number of flowers obtained in the open field was 11. After 3 months, in the fruiting stage, the two plants fruited 7 chilies.

The average height of the plants in vegetative stage inside the greenhouse was much greater than the average height of plants in the open field. This is because the greenhouse plants were growing in a sheltered environment (greenhouse) and water was supplied automatically by fertigation . The plants in the open field were watered manually and exposed to the natural environment. The chili yield from the open-field plants was higher compared to that from the greenhouse plants although the number of flowering plants inside the greenhouse was higher than in the open field. It is believed that the process of pollination was not successful due to low presence of pollinators such as insects and wind inside the greenhouse. If this problem can be effectively solved, it is believed that the yield of chilies inside the greenhouse would be higher.

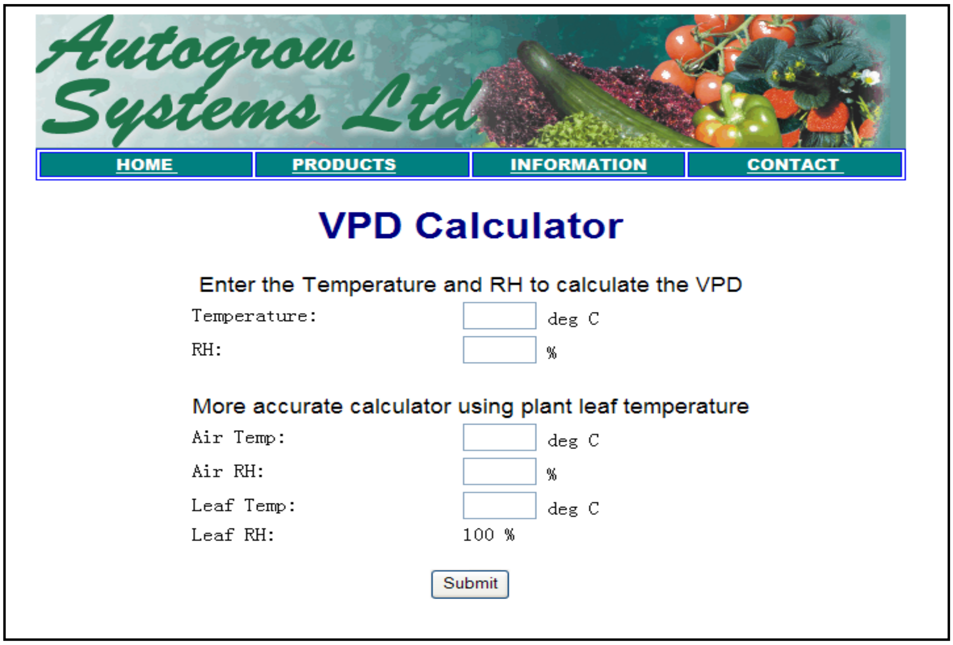

Fig.8: The Online VPD Calculator

The relative humidity (RH), temperature (T) and VPD for the chili plant are 55%, 17°C and 0.85 kPa respectively. GUI will run when it meets these conditions:

i. RH=55% and T=17°C

No actuator was keyed in in the GUI check-list box for conditions that reached RH = 55% T = 17°C . This was due to the fact that the temperature and RH had reached optimum conditions inside the greenhouse. This, therefore, illustrates that no actuator was activated by the control system.

ii. RH=45% and T=34°C

"Fogging" was activated as in the system check list when RH reached 45% and T reached 34 °C. Based on the scope of the programming that was written, the fogger was activated if the RH were less than the set-point, 55%. The fan and the swamp cooler would then be deactivated.

iii. RH=55% and T=20°C

When conditions inside the greenhouse reached RH=55% and T=20°C, all the actuators were activated via the GUI system check list. RH reached its set-point but T was higher than its set-point. Therefore, all actuators were activated to lower the temperature in the greenhouse until it reached the set-point, 17°C. This means that the user need not be present in or near the greenhouse to know which actuator is running as this can be monitored and adjusted by the GUI.

CONCLUSION

A data acquisition system to control the temperature and relative humidity of a greenhouse was successfully developed and used to record data every 30 minutes inside and outside the greenhouse. The data acquisition system was able to monitor the growth of the plants in the greenhouse via the control system. A PIC controller was successfully used and interfacing with a computer (read data) was achieved. The plant i.e. chili yield in the control sector i.e. an open field was observed to be higher compared to that of the greenhouse although the number of flowering plants inside the greenhouse was higher than in the open field. It is believed that the process of fertilisation was not successful due to low presence of pollinators such as insects or wind inside the greenhouse. If this problem can be successfully addressed, it is believed that the yield of chilies inside the greenhouse will be higher. Due to the fact that the greenhouse provides a shelter for plant cultivation under a roof system, the environment parameters can be controlled to suit the type of crop using computer applications and a sensory system.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Higher Education for the FRGS grant on 'Development of Automation Control System for Lowland Greenhouse Crop Production' to do this research work.

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