Faculty of Engineering

Environmental Monitoring and Simulation Study of Young Sago Palms Cultivated in Mist Chambers

Kho Ee Ping

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Environmental Monitoring and Simulation Study of Young Sago Palms Cultivated in Mist Chambers

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Signature

Name: Kho Ee Ping

Matric No.: 18020134

Faculty of Engineering

Universiti Malaysia Sarawak

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ABSTRACT

Environmental monitoring is important as it manages the critical factors required for sustainable plants' growth and development. In this thesis, the development of a wireless sensor network (WSN) monitoring system for young sago palms in mist chambers is presented. The effect of the functional system on the environment parameters monitored was also investigated. The system was set up to monitor three environmental factors i.e., temperature, relative humidity, and light intensity. The system is equipped with the functionality to record instantaneous readings at every 15-min interval using multiple sensors and control the opening for natural ventilation using linear actuators. It is also embedded with a smart alert system and an online monitoring portal. Data transmission was achieved using the Zigbee network and GPRS gateway. To evaluate the effect of the functional system, the temperature reduction through natural ventilation was analysed through computational fluid dynamics (CFD) simulation. The simulation was run using ANSYS Fluent software and was validated with experimental data. The ventilation efficacy was examined through two parameters, i.e., temperature heterogeneity (H_t) and ventilation flow rate (VFR). The greatest temperature reduction within the mist chamber was found to be 10.5% with natural ventilation. In conclusion, a WSN system for mist chambers in a sago palm greenhouse was successfully developed to real-time monitor the plant growing environment through data acquisition, data transmission and data visualisation. The developed WSN system is also capable of providing a suitable microclimate for young sago palms' growth and development.

Keywords: Sago palm, environmental monitoring, wireless sensor network, thermal study, computational fluid dynamics

Pemantaun Alam Sekitar dan Kajian Simulasi Terhadap Tanaman Sagu Muda yang Ditanam di dalam Ruang Kabus

ABSTRAK

Pemantauan alam sekitar adalah penting kerana menguruskan faktor-faktor kritikal yang diperlukan untuk kelestarian pertumbuhan dan perkembangan tanaman. Dalam tesis ini, pembangunan sistem pemantauan rangkaian sensor tanpa wayar (WSN) untuk tanaman sagu muda di ruang kabus disajikan. Kesan sistem berfungsi pada parameter persekitaran yang dipantau juga disiasat. Sistem ini dibentuk untuk memantau tiga faktor persekitaran iaitu., suhu, kelembapan relatif, dan intensiti cahaya. Sistem ini dilengkapi dengan fungsi untuk merakam bacaan seketika pada setiap selang 15 minit dengan menggunakan beberapa sensor dan mengawal bukaan untuk pengudaraan semula jadi dengan menggunakan penggerak linier. Ia juga dibina dengan sistem amaran pintar dan portal pemantauan dalam talian. Penghantaran data dicapai dengan menggunakan rangkaian Zigbee dan gerbang GPRS. Untuk menilai keberkesanan sistem berfungsi, pengurangan suhu melalui pengudaraan semula jadi dianalisa melalui simulasi dinamika cecair komputasi. Simulasi dijalankan dengan menggunakan perisian ANSYS Fluent dan disahkan dengan data eksperimen. Keberkesanan pengudaraan diperiksa melalui dua parameter, iaitu., heterogenitas suhu (Ht) dan kadar aliran udara (VFR). Pengurangan suhu terbesar di ruang kabus didapati 10.5% dengan pengudaraan semula jadi. Kesimpulannya, sistem WSN untuk ruang kabus di rumah hijau tanaman sagu muda berjaya dikembangkan untuk memantau persekitaran tanaman melalui pemerolehan data, penghantaran data dan visualisasi data secara masa serentak. Sistem WSN yang dibangunkan juga mampu menyediakan iklim mikro yang sesuai untuk pertumbuhan dan perkembangan tanaman sagu muda.

Kata kunci: *Sagu, pemantauan alam sekitar, rangkaian sensor tanpa wayar, kajian terma, dinamika cecair komputasi*

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ACH	Air changes per hour
API	Application Programming Interface
CFD	Computational Fluid Dynamics
FMC	Fully Enclosed Mist Chamber
GPRS	General Packet Radio Service
GSM	Global Service Messaging
HDPE	High Density Polyethylene
IoT	Internet of Things
MAE	Mean Absolute Error
MC	Mist Chamber
PLA	Polylactic Acid
PMC	Partially Enclosed Mist Chamber
RF	Radio Frequency
RMSE	Root Mean Square Error
SIM	Subscriber Identification Module
SMS	Short Messaging Services
UAV	Unmanned Aerial Vehicle
VFR	Ventilation Flow Rate
WSN	Wireless Sensor Network
ZB	ZigBee

CHAPTER 1

INTRODUCTION

1.1 Study Background

Sago palm (Metroxylon sagu) is one of the valuable commodities that is largely cultivated in Southeast Asia particularly the state of Sarawak, Malaysia due to its high starch content. Sago palm is mainly cultivated in small sago farms and commercial sago plantations. Due to the long yielding time of sago palm, it is crucial to maintain the high quality and productivity of sago palm during cultivation. CRAUN Research Sdn Bhd has taken the responsibility of producing high quality young sago palm plantlets through tissue culture techniques and providing them to the sago farms and plantations every month.

These sago palms cloned through tissue culture are nurtured in the lab environment with a precisely controlled climate of temperature, relative humidity, and light intensity. After they have developed into young plantlets, they are switched from the lab environment to the mist chambers in the sago palm greenhouse for a month, as shown in Figure 1.1. In the mist chamber, the young sago palms are watered by mist sprays four times a day to retain a high humidity environment. Subsequently one month later, the sago palms are moved out from the mist chambers and continue planted in the greenhouse. When the sago palms are mature enough to be planted in field conditions, they would be transferred to the open land area and waiting to be transported to the local sago farms and plantations. These phase-to-phase adaptations and assimilation processes are to ensure the sago palms bred through tissue culture could survive and grow well from controlled conditions to real harsh conditions at the field.

Figure 1.1: Top, *in vitro* young sago palms taken directly from the lab; bottom, young sago palms transplanted in pots before planting out in the mist chamber

The changing climate due to global warming nowadays has imposed shifts in the microclimate inside the mist chambers indirectly. In most cases, the mist chambers could be too hot for these young clonal sago palms to survive. Adjustments to the microclimate inside the mist chambers should be done for precision agriculture. Nevertheless, there is no idea of

the current reading of the environmental parameters in the mist chamber due to the lack of continuous measurement. As a result, the effect of these adjustments could not be evaluated because it is impossible to know the difference between the original microclimate and the adjusted microclimate. Most agricultural decisions are done executed human intuitions. For instance, when the weather feels like it is hot, the workers would manually open the mist chamber doors to leave small gaps. There is inconsistency in the gap opening size and the duration for leaving the doors partially open. More importantly, the efficiency of partially opening the mist chamber doors for natural ventilation is unknown.

Digital monitoring systems are gaining attention in the agricultural field nowadays because digital monitoring systems could overcome the human limitation in measuring the environmental parameters continuously, precisely and instantaneously. The most popular digital monitoring system being widely applied is the WSN monitoring system. It has many advantages over traditional wired systems. Without the engagement of wires, WSN systems could be applied over a larger coverage area. The maximum distance is only restricted by the wireless communication range depending on the chosen protocol. It could be scalable by adding or removing sensor nodes and hence suitable for the changing demand. Another major benefit of WSN monitoring systems is that all data are usually integrated into one place and could be easily accessed. Along with the advancement in the internet of things (IoT) technology, these data often are stored online. There are more possibilities in applications when all the data are integrated online, such as irrigation scheduling and control, remote monitoring etc.

With the aid of the WSN monitoring system, it is feasible to analyse the effect of the adjustments to the microclimate inside the mist chamber. It is uttermost important to

understand the effect of natural ventilation on the mist chamber microclimate. By comparing the data, it is possible to detect the changes in the environmental parameters and evaluate its efficacy. To further justify the findings, CFD is a useful tool to simulate the environmental conditions prior to and after the adjustments. The employment of CFD simulation could provide a better idea of the heat transfer mechanisms in terms of airflow during natural ventilation.

1.2 Problem Statement

Presently the young sago palms planted in the mist chambers are subjected to heat stress due to the thermal accumulation in the mist chambers as the heat could not escape from the mist chamber. Under extreme heat stress, it could lead to a high mortality rate among young sago palms. The current practice of lowering down the temperature in the mist chambers is achieved through partially opening the mist chamber doors manually by the workers during the day. However, the partial opening of the mist chamber doors also indicates a drop in relative humidity. The current practice is inefficient and could not know the actual real-time readings of temperature and relative humidity, resulting in poor decisions based on subjective perceptions. The efficacy of partially opening the mist chambers manually for temperature reduction is also unknown.

1.3 Research Questions

The existing problems have raised a series of research questions that are described as follow.

i. What are the possible ways to measure the environmental data inside the mist chamber continuously and simultaneously from different mist chambers?

ii. How to eliminate the human effort and automate the process of partially opening and closing the mist chamber doors for natural ventilation?

iii. Is partially opening the mist chamber doors for natural ventilation effective for reducing the temperature inside the mist chamber?

1.4 Objectives

The research primarily aims to achieve the following set of objectives:

i. To develop a WSN system that can be used to real-time monitor the sago palm mist chambers through data acquisition, data transmission, data visualisation and data application.

ii. To develop an automated system to control the partial opening and closing of the mist chamber doors for natural ventilation based on threshold temperature as an application of the acquired data.

iii. To analyse the effect of natural ventilation on the thermal accumulation in the mist chamber through a CFD simulation.

1.5 Hypothesis

The following hypotheses have been outlined for the research study:

i. With implemented WSN monitoring system, the microclimate inside the mist chamber where the sago palms are grown could be thoroughly known and could aid in precision agriculture.

ii. Digital monitoring systems like the WSN monitoring system could real-time collect more data from different mist chambers and integrate them all in one

place compared to the limitation in the manual reading of environmental parameters.

iii. Linear actuators are suitable to control the partial opening and closing of mist chamber doors and could be activated or deactivated through temperature values.

iv. Natural ventilation is effective in lowering down the temperature inside the mist chamber to avoid heat stress in sago palms.

1.6 Research Gap

WSN technology has been widely applied in the agricultural field in many aspects, for instance environmental monitoring being one of them. WSN monitoring systems is quite common for many commercial crops that are cultivated in greenhouses and many related studies could be found in the literature (Guzmán et al., 2019; Martinović & Simon, 2014; Noh et al., 2017; Pawlowski et al., 2016; Rajasekaran & Anandamurugan, 2019). To date, there is no digital monitoring system has been applied to monitor the environmental conditions of young clonal sago palms that are grown in the mist chambers. Similarly, analysis of thermal behaviour and airflow inside the mist chamber is rare in the literature whereby most case studies focus on the greenhouse climate ((Ahemd et al., 2016; Haijun et al., 2015; Mahmood et al., 2018; Zhao et al., 2012). Therefore, this research study fills in the gap to cover the specific applications of WSN in mist chambers as well as the CFD simulation study of microclimate inside the mist chamber.

1.7 Scope of Study

This research study covers the development of a WSN monitoring system to monitor the environmental parameters (temperature, relative humidity, and light intensity) of the surrounding ambient and microclimate inside different mist chambers, i.e., Mist Chamber A, Mist Chamber B and Mist Chamber C in CRAUN Research Sdn. Bhd. Among all mist chambers, only Mist Chamber B and Mist Chamber C are equipped with linear actuator applications to control the partial opening and closing of mist chamber doors for natural ventilation. Mist Chamber A is defined as a control set. The work also includes the evaluation of the natural ventilation efficacy in the mist chamber through CFD simulation using ANSYS Fluent software.

1.8 Chapter Summary

Young sago palms bred through tissue culture are grown in the mist chambers inside the greenhouse after moving out from the lab and before planting out to the actual field conditions. The mist chambers trap heat easily and may impose heat stress on the young sago palms, thus leading to a high mortality rate. To lower down the temperature inside the mist chambers, the workers manually open the mist chamber doors partially. The current practice is inefficient and could not know the actual real-time readings of temperature and relative humidity, resulting in poor decisions based on subjective perceptions. The efficacy of partially opening the mist chamber doors manually for temperature reduction is also unknown. Therefore, it is desired to develop a real-time WSN monitoring system for the sago palm mist chambers while at the same time automatically controlling the partial opening and closing of the mist chamber doors. It is also important to understand the effect of natural ventilation on the thermal accumulation inside the mist chamber through a CFD simulation study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This section discusses the background of sago palm, tissue culture in sago palm, the environmental effects towards sago palm, the demand of environmental monitoring, various environmental monitoring techniques, thermal accumulation in mist chamber, cooling strategies and CFD simulation.

2.2 Background of Sago Palm

Sago (Metroxylon sagu Rottb.) is a palm species naturally grown in countries like Malaysia, Thailand, Indonesia, Papua New Guinea, Philippines and the Solomon Islands. Sago palm has been a promising economic commodity because it is the world's highest starch producer at 25t/ha/year, 4 times higher than rice, 5 times than corn and wheat and nearly 17 times of tapioca (Flores, 2008; Ishizaki, 1997). Apart from being high yielding, sago starch has a low cost of production when compared to other sources of starch (Fasihuddin & Williams, 1996). Studies have revealed that sago has diversified usage in food industries like encapsulating flavour, thickening sauces and soups, offering better gelling characteristics, and giving prolonged crispiness. In non-food industries, sago starch is used as a coating agent in the biodegradable film, thickener in adhesive preparation and printing, sizing agents in papermaking, dusting powder in cosmetic, hypoallergenic powder and bioethanol production (Bujang, 2014; Mohamad Naim et al., 2016; Singhal et al., 2008). Aside from its economic value, sago palm is a versatile plant that could tolerant to harsh conditions like acidic soil, sulfidic soil, waterlogged soil, alluvial soil, sandy soils, peat soil, clay soil, volcanic soil, podzolic soil, saline soil, grumusol and hydromorphic soil (Djoefrie