DEVELOPMENT OF A FUZZY CONTROLLER FOR TUBERS POST-HARVEST STORAGE SYSTEM

BY

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ABSTRACT

In many countries, substantial amount of agricultural products, including root and tuber crops, which cannot be consumed, processed, commercialized, transported or exported are produced on daily basis. However, facilities for adequate and efficient post-harvest storage and preservation of these products are not readily available, especially in most developing countries, resulting in considerable losses. Hence, the need for improved, adequate and efficient food storage and preservation systems. Nowadays, traditional methods for post-harvest storage and preservation of tropical roots and tubers such as yam barn, underground pits, leaving matured tuber buried in the ground until need arises, and trench silos are employed for the storage and preservation of these crops. Unfortunately, all these storage techniques leads to undesirable results as the stored products are susceptible to uncontrollable environmental conditions such as temperature and relative humidity, which leads to significant losses, reduction in quality and quantity of the products as well as their market prices. Sustaining appropriate temperature and relative humidity of the storage environment is crucial to achieving better storage objectives. However, at present, only few studies have utilized the unique advantages of intelligent techniques to improve the conditions of indigenous roots and tubers post-harvest storage and preservation system. An intelligent post-harvest tropical root and tuber crops storage system is proposed and developed in this research work. The post-harvest storage system adopts the fuzzy logic control (FLC) strategy for optimum control of temperature and relative humidity of selected tropical tuber crop. In this thesis, yam (*Dioscorea spp.*) is considered for optimum control of its storage temperature and relative humidity (tracking of its desired storage temperature and relative humidity). In order to maintain optimum storage conditions, forced-air cooling is employed to ensure proper ventilation within the storage compartments. Temperature and relative humidity sensor was used to determine the property of the conditioned air supplied by the cooling system and provides necessary feedback. To test the performance of the intelligent controller for keeping the produce (yam tubers) storage temperature and relative humidity requirements within acceptable range, simulation studies were carried out in MATLAB/SIMULINK simulation environment and experimental validation on existing post-harvest tropical food storage system prototype using DSP chip as interfacing module was performed. Results obtained show that the developed controller is able to track the desired temperature and relative humidity set-points for each product under storage with a settling time of 5.6s and 4.63s respectively, and responds accordingly to input disturbances to ensure better storage objectives are achieved successfully.

خلاصة البحث

في العديد من البلدان، ويتم إنتاج كمية كبيرة من المنتجات الزراعية، بما في ذلك المحاصيل الجذرية والدرنية، والتي لا يمكن استهلاكها، وتجهيزها، تسويقها ونقلها أو تصديرها على أساس يومي .ومع ذلك، ومرافق للالكافي وكفاءة التخزين بعد الحصاد والحفاظ على هذه المنتجات ليست متاحة بسهولة، وخاصة في معظم البلدان النامية، مما أدى إلى خسائر كبيرة .وبالتالي، فإن الحاجة إلى أنظمة تخزين المواد الغذائية وحفظها تحسين وكافية وفعالة .في الوقت الحاضر، يتم استخدام الأساليب التقليدية لتخزين ما بعد الحصاد والمحافظة على الجذور والدرنات الاستوائية مثل الحظيرة اليام، حفر تحت الأرض، وترك درنة نضجت مدفونة في الأرض حتى تنشأ الحاجة، وصوامع خندق لتخزين والحفاظ على هذه المحاصيل .للأسف، كل تقنيات تخزين هذه تؤدي إلى نتائج غير مرغوب فيها والمنتجات المخزنة عرضة للظروف البيئية لا يمكن السيطرة عليها مثل درجة الحرارة والرطوبة النسبية، الأمر الذي يؤدي إلى خسائر كبيرة، وانخفاض نوعية وكمية المنتجات فضلا عن أسعارها في السوق .الحفاظ على درجة الحرارة المناسبة والرطوبة النسبية للبيئة التخزين أمر بالغ الأهمية لتحقيق الأهداف تخزين أفضل .ومع ذلك، في الوقت الحاضر، لا يوجد دليل على التطبيقات التي وظفت فيها مزايا فريدة من تقنيات ذكية لتحسين ظروف الجذور الأصلية والدرنات التخزين بعد الحصاد ونظام المحافظة .ويقترح جذر الاستوائية بعد الحصاد والمحاصيل الدرنية نظام التخزين الذكية والمتقدمة في هذا العمل البحثي .نظام التخزين بعد الحصاد يعتمد على سيطرة منطق غامض (FLC) استراتيجية لمكافحة المثلى من درجة الحرارة والرطوبة النسبية للمحاصيل الدرنية الاستوائية المحدد .في هذه الأطروحة، ويعتبر اليام *Dioscorea*)النيابة (.للسيطرة المثلى لدرجة حرارة التخزين والرطوبة النسبية) تتبع لها درجة حرارة التخزين المطلوبة والرطوبة النسبية .(من أجل الحفاظ على ظروف التخزين المثلى، ويعمل تبريد الهواء القسري لضمان التهوية المناسبة داخل حجرات التخزين .واستخدمت درجة الحرارة والرطوبة النسبية وأجهزة الاستشعار لتحديد ملكا للهواء توفيره من قبل نظام التبريد، ويقدم التغذية المرتدة اللازمة .لاختبار أداء وحدة تحكم ذكية للحفاظ على كل منتج) جذور الكسافا والبطاطا الحلوة والبطاطا الدرنات (درجة حرارة التخزين ومتطلبات الرطوبة النسبية داخل نطاق مقبول، وأجريت دراسات المحاكاة في MATLAB / SIMULINK بيئة المحاكاة والتحقق التجريبي على ما بعد الحصاد الحالي تم تنفيذ نظام تخزين المواد الغذائية الاستوائية النموذج باستخدام رقاقة DSP كما تفاعل وحدة .النتائج التي تم الحصول عليها تظهر أن وحدة تحكم المتقدمة غير قادرة على تتبع درجة الحرارة المطلوبة والرطوبة النسبية مجموعة نقاط لكل منتج تحت التخزين ويستجيب وفقا لذلك إلى اضطرابات مساهمة في ضمان تحقيق أهداف تخزين أفضل بنجاح.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Mechatronics Engineering.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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To my late brother and sister, may Allah (S.W.T) forgive your shortcomings and make Al-jannatul firdaus your final abode

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LIST OF ABBREVIATIONS

ADC	Analog-to-digital converter
ALUs	Arithmetic logic units
ANFIS	Adaptive neuro-fuzzy inference system
ANNs	Artificial neural networks
ASICs	Application specific integrated circuits
CI	Chilling injury
COA	Center-of-Area
D. *alata*	Dioscorea *alata*
D. *bulbifera*	Dioscorea *bulbifera*
D. *cayenensis*	Dioscorea *cayenensis*
D. *dumetorum*	Dioscorea *dumetorum*
D. *esculenta*	Dioscorea *esculenta*
D. *rotundata*	Dioscorea *rotundata*
D. *trifida*	Dioscorea *trifida*
DAC	Digital-to-analog converter
DBBs	Digital building blocks
DC	Direct current
DSL	Digital subscriber loop
DSP	Digital Signal Processing
DSPs	Digital Signal Processors
FFT	Fast Fourier transform
FLC	Fuzzy logic control
FLS	Fuzzy logic system
GAs	Genetic algorithms
H	High
IC	Integrated circuit
L	Low
M	Maximum
MAC	Multiply and accumulate
MD	Medium
MIMO	Multi-input-multi-output
MIPS	Million instructions per second
N	negative
NB	Negative big
NS	Negative small
Op-Amp	Operational amplifier
P	Positive
PB	Positive big
PC	Personal computer
PID	Proportional-Integral-Derivative
PS	Positive small
PWM	Pulse-Width modulation
RH	Relative humidity
S	Stop
USB	Universal serial bus
Z	Zero

LIST OF SYMBOLS

Q_{vacuum}	Amount of heat from remove from produce
m_v	Mass of water evaporated
h_{fg}	Heat of vaporization of water
K_P	Proportional gain
K_I	Integral gain.
K_D	Derivative gain.
μP	Microprocessor
E_T	Temperature error
E_H	Humidity error
$\dot{E}_T$	Temperature error derivative
$\dot{E}_H$	Humidity error derivative
ΔU_A	Change in cooling fan speed
ΔU_B	Change in circulating fan speed
ΔU_H	Change in humidifier exhaust fan speed
$\dot{M}_m$	Moisture injection rate
T_{cia}	Conditioned-inlet air temperature
T_{ac}	Actual storage temperature
RH_{ac}	Actual storage relative humidity
$T_{ref.}$	Reference temperature
$RH_{ref.}$	Reference relative humidity

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Post-harvest storage is one of the several stages of post-harvest activities that follows immediately after harvest of agricultural products in order to sustain the product quality and quantity, reduce post-harvest losses and to guarantee food security by ensuring its availability even in period of scarcity. However, recent statistics have shown that, post-harvest losses of stored agricultural products are substantially high ranging from 25 to 40% of stored products due to inadequate and inefficient storage facilities especially in developing Nations (Abdulazeez, Salami, & Tijani, 2011). Hence, the need for improved, adequate and efficient post-harvest storage and preservation facilities is emphasized.

In addition to inadequate and inefficient post-harvest storage and preservation facilities, various factors such as respiration, transpiration and sprouting have been found responsible for these losses. Others include attack by mammals, birds and insect, rot due to mould and spoilage as a result of bacterial activities. Respiration, transpiration and sprouting are physiological processes which depends so much on temperature and relative humidity of storage environment, and have been identified as the major causes of post-harvest losses of stored agricultural products (Osunde, 2008). To control these physiological processes, therefore, maintaining appropriate temperature and relative humidity of the storage environment is significant.

Yam tuber (Dioscoreaceae; *Dioscorea spp*) is an edible starchy tuber grown predominantly in tropical regions of the world. After cassava, yam is the next most important staple food crop in West Africa and Southeast Asia (Adeyinka, Momoh-

Jimoh, Raisuddin, & Musa, 2011; Opara, 2003) with tremendous economic contributions to these regions. Several species of yam are available, however, only white yam (*D. rotundata*), water yam (*D. alata*), yellow yam (*D. Cayenensis*), aerial yam (*D. bulbifera*), Chinese yam (*D. esculenta*) and trifoliate yam (*D. dumetorum*) are considered significant staple food in tropical regions (Opara, 2003; Osunde, 2008). Unlike other tropical fresh produce, such as cassava, yam can last relatively longer under storage, hence, stored yam represents stored wealth which can be commercialized throughout the year by the farmers or sellers (Adeyinka et al., 2011; Opara, 2003). Recently, there is an increasing export demands of yam tubers which is another factor responsible for the choice of yam in this research. Figure 1.1 shows a typical yam tuber (Adeyinka et al., 2011). For good post-harvest storage and preservation of yam tubers, 15-16^{o}C temperature range and 70-80% relative humidity has been recommended with expected 6-7 months storage life under these conditions regardless of cultivars (Opara, 2003).

Figure 1.1 A complete and a slice of yam tuber (Adeyinka et al., 2011)

Literatures have revealed that, most of the techniques used for yam tubers post-harvest storage and preservation are traditional methods such as leaving the tubers beneath the earth until need arises, underground structures, stringing (hanging), yam barns, yam tubers left in the ridges after maturity, heap storage, trench silos, conical protective roof and platform storage among others (Adeyinka et al., 2011). However, it's reported that, all these storage methods are characterized by heavy losses which could be in the range of 30-60% of the stored agricultural products in 3-6 months of storage duration depending on the species and storage environment as the produce are susceptible to uncontrollable environment, harsh climatic conditions, physical attack by rodents, birds, insect, and mammals, as well as fungal and bacterial diseases (Abdulazeez et al., 2011). Refrigeration at temperatures between 13-17^{o}C and maintaining storage relative humidity at 70-80% have been shown to minimizes yam tubers post-harvest losses considerably and improve the produce shelf life (Abdulazeez et al., 2011; Opara, 2003). However, due to erratic and fluctuations in power supply in some regions, high cost for man power required to maintain the equipment, and financial cost of the equipment, the use of automatic and intelligent control strategy is proposed in this study. Intelligent control methods has the potential to minimize some of these challenges and consequently improve the storage duration for yam tubers. In this research, the development of an intelligent controller for optimal control of storage temperature and relative humidity levels within yam tubers post-harvest storage and preservation system using fuzzy logic control (FLC) method is presented. The developed fuzzy control algorithm is implemented using digital signal processor (DSP) as an interfacing (data acquisition device) module and used in real-time for control of the existing post-harvest storage system prototype. The choice of DSP is due to its high computational capability, speed and processing power to execute control algorithm for real-time control applications. Due to its flexibility, low operation cost, good efficiency, low maintenance requirements and lack of leakage problems (Ambaw et al., 2013), forced-air cooling method was adopted for proper ventilation of the tubers under storage.

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

Post-harvest losses of agricultural produce has been reported as one of the main causes of food shortage in the World (Dreze & Sen, 1991). In an attempt to minimize these losses, indigenous post-harvest storage methods such as leaving the tubers in ground until need arises, yam barns, trench silos and platform storage methods have been employed in most developing countries. However, these storage methods are characterized by substantial losses which could be about 30-60% of the stored produce (Abdulazeez et al., 2011). For successful post-harvest storage and preservation of yam tubers, adequate aeration of the storage environment and maintaining appropriate storage temperature and relative humidity is significant. As pointed out by (Osunde, 2008), storage temperature and relative humidity are known to be the major factors responsible for these substantial losses. Inappropriate storage temperature and relative humidity leads to:

a. Temperature effect: High storage temperature causes an increase in tubers respiration, rotting and sprouting of the tubers under storage and subsequently leads to their physiological deteriorations which results in considerable losses by damaging the physiological structure of the tubers. At lower storage temperatures, physiological deteriorations of the tubers such as chilling injury could occur.

b. Humidity effect: Inadequate aeration of the storage environment leads to moisture build-up or condensation on the produce surface and consequently makes removal of heat emitted due to respiration difficult. High storage relative humidity enhances tuber rotting and decay as a result of mould formation and hence, destroys the edible portion and nutritional value of the produce. Dryness, shrinkage and loss in weight of tubers occur at lower storage relative humidity. This affects the produce cooking quality and its market prices significantly.

c. Insects and mammals attack: Agricultural produce under storage, including yam tubers, are often prone to attack by insect, birds and mammals such as rodents, and other pests that hide themselves inside the storage environment. Also, exposure to microbial actions such fungi, yeasts and bacterial cause serious damage to the produce which leads to considerable losses by destroying the edible part thereby affecting the nutritional values of the produce.

Despite of the fact that, several traditional storage methods have been proposed, they have many disadvantages such as inadequate aeration and moisture condensation on produce surface which leads to considerable losses by enhancing physiological deteriorations. What is however required is an intelligent control technique that is simple, safe, efficient and can effectively maintain appropriate storage conditions within recommended levels. In this regard, a fuzzy logic control strategy is suggested for control of the post-harvest storage system that can appropriately control the storage temperature and relative humidity within suitable limits.

1.3 RESEARCH OBJECTIVES

The primary objective of this research is to develop a fuzzy logic control algorithm using DSP chip as an interface for real-time control of storage temperature and relative humidity within yam tubers post-harvest storage and preservation system.

In order to achieve this objective, the following sub-objectives must be completed.

1. Development of fuzzy logic algorithm for storage temperature and relative humidity control within yam tubers post-harvest storage and preservation system.
2. Development of DSP-Based hardware system for real-time control of the post-harvest storage process.
3. Real-time performance evaluation of the DSP-based fuzzy logic controller using an existing post-harvest storage system.

1.4 RESEARCH METHODOLOGY

The following approach is adopted in order to achieve the objective of this study.

1. **Literature Review**

   An intensive literature review of books, journal papers and articles is done focusing mainly on intelligent control techniques, existing storage techniques used for the storage and preservation of agricultural products, cooling methods employed for the preservation of agricultural products, and to acquire information on various characteristics and areas of application of DSP chip order to be conversant with the present state-of-the-art in these areas of research.

2. **Description of the proposed system**

   Based on the information obtain from literature survey, the proposed storage system dynamics behaviour is studied and fully described and control objectives were established based on this.

3. **Development of the intelligent controller**

   The intelligent controller is then developed for optimal storage temperature and relative humidity (tracking) control based on fuzzy logic control strategy. The fuzzy logic controller consist of two sub-controllers: fuzzy temperature controller and fuzzy humidity controller.

4. **Real-time Performance evaluation of the developed controller**

   The controller developed in stage (2) is then implemented using a DSP chip as an interfacing module and substantiated for its control objectives by real-time experimentation using an existing storage system prototype.

5. **Result Analysis**

   The results obtain are evaluated to ascertain its conformity with the control objectives and to see areas of improvement where necessary.

Figure 1.2 illustrates the flow chart for the research methodology.

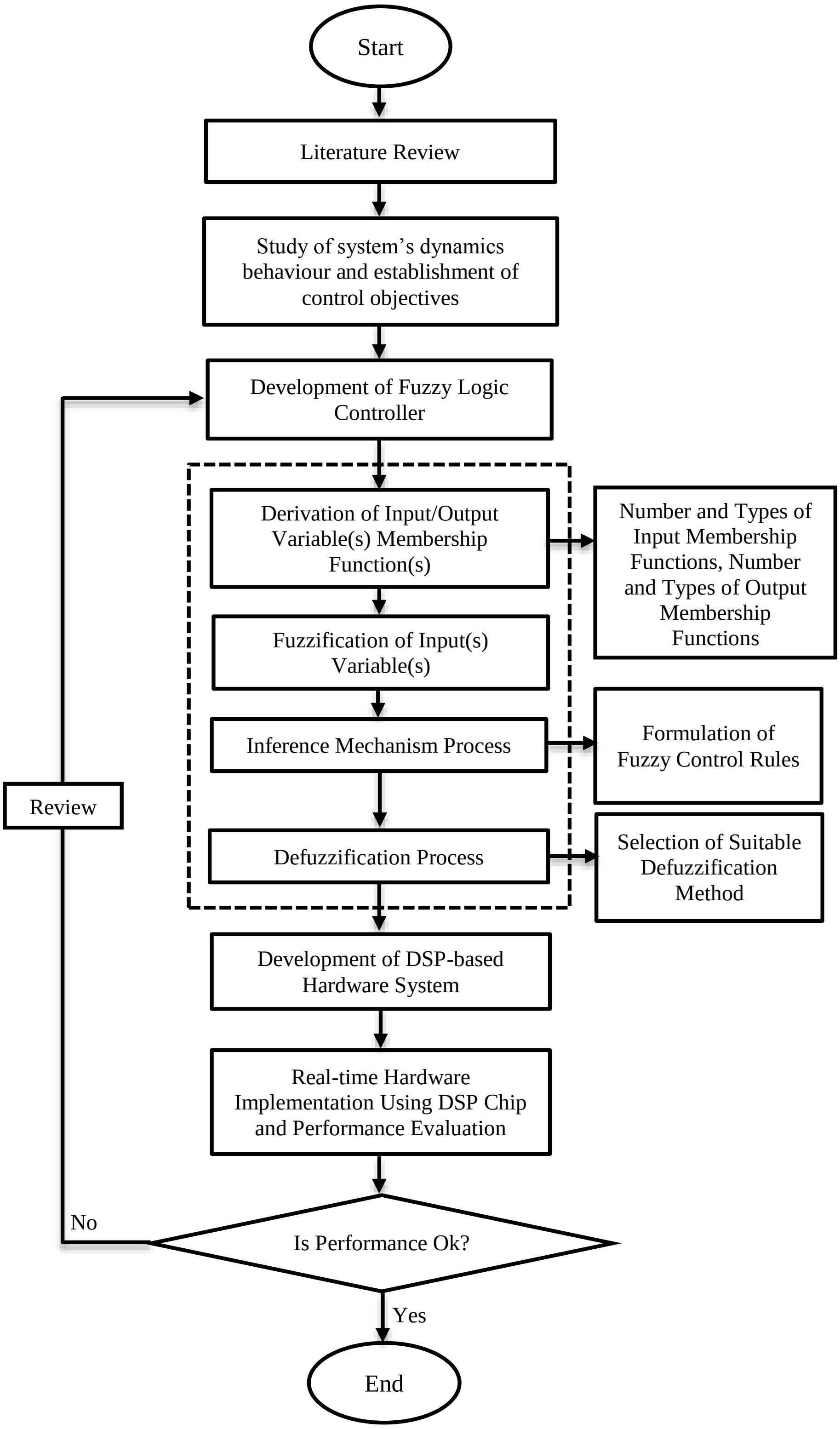

Figure 1.2 Schematic of the Research Methodology Flowchart