UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A NEURAL NETWORK-BASED CAMERA FOR TOMATO HARVESTING ROBOTS

AZIZ BIN MAMAT

DEVELOPMENT OF A NEURAL NETWORK-BASED CAMERA FOR TOMATO HARVESTING ROBOTS

by

AZIZ BIN MAMAT

Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfilment of the requirements for the Degree of Master Of Science

December, 2008

Dedicated to my parents,

Hj. Mamat Bin Hj. Awang and Hjh. Habsah Binti Hj. Awang Kechik

My beloved wife,

Hjh. Sazilawati Binti Abdul Aziz

My beloved daughter and sons,

Nurul Afina Binti Aziz

Zaim Raziqin Bin Aziz

Zaim Wafiuddin Bin Aziz

and

friends

with love.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

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Chairman : Professor Wan Ishak Wan Ismail, PhD

Faculty : Engineering

Automated tomato harvesting robots were rapidly developed recently. Most of the designs were more focused on positioning of the end of robotic arm by using various methods such as combination of the sensor and vision system. This project concentrated on the artificial intelligent via the Neural Network, in order to provide a better decision making system for tomato harvesting robot. The objective of this study was to develop 3 degree of freedom tomato harvesting robotic system complete with gripper and motion program. The development of software for tomato pattern identification, determination of the X and Y coordinates from web camera captured and the determination of the tomato and tomato ripeness using decision making from Neural Network also become the main objective. The approach is to detect the desired object using vision system attached to the cylindrical automation system and perform image analysis. These features will serve as inputs to a neural net, which will be trained with a set of predetermined ripe tomato. The output is a command for harvester arm to make the movement for harvesting. The position determination was done with a conversion of the distance in pixel into a distance in metric unit (mm) of

the tomato image. Whereas the depth of the tomato distance (z direction) was done by moving the actuator system towards the calculated tomato position until the object sensor senses the present of the tomato. AWIsoft07 software was developed to view the harvester vision, display the captured image analysis on the harvester vision, and display the numerical analysis output and neural network output.

The harvester system with 3 degree of freedoms (3DOF) equips with specially designed tomato gripper named as AWI2007 Tomato Harvesting Robot was developed in order to realize the data from the AWISoft07 developed software. Several calibrations were made to ensure the accuracy of the AWI2007 Tomato Harvesting Robot. The AWIsoft07 and AWI2007 Tomato Harvesting Robot were subjected to several harvesting tests under the laboratory environment. The harvesting result shows the ability of the software and the harvester. Consequently, AWI2007 Tomato Harvesting Robot with the camera vision was able to recognize the tomato ripeness intelligently via neural network analysis and moved to the harvesting position. These situations provided new improvements for tomato harvesting system compared to the previous findings. Therefore the application of the neural network based on camera vision was successful perform as artificial intelligent for tomato harvesting robotic system.

Abstrak tesis dikemukan kepada Senat Universiti Putra Malaysia sebagai memnuhi keperluan untuk ijazah Master Sains

MEMBINA NEURAL NETWORK BERASASKAN KAMERA UNTUK ROBOT PENUAIAN TOMATO

Oleh

AZIZ BIN MAMAT

Disember 2008

Pengerusi : Professor Wan Ishak Wan Ismail, PhD

Fakulti : Kejuruteraan

Robot penuaian tomato yang beroperasi secara outomatik telah dibina secara rancak kebelakangan ini. Kebanyakan rekabentuknya memfokuskan kepada penentuan kedudukan pengesan hujung lengan robot dengan menggunakan berbagai kaedah seperti kombinasi sensor dan sistem penglihatan. Projek ini menumpukan kepada kepintaran tiruan melalui Jaringan Neural, dalam menyediakan sistem pembuatan keputusan untuk robot penuaian tomato. Objektif kajian ini adalah membangunkan robot penuaian tomato dengan tiga darjah kebebasan, lengkap dengan penggengam dan program pergerakan. Pembangunan perisisan untuk identifikasi bentuk tomato, menentukan koodinat X dan Y daripada rakaman imej kamera sesawang dan menentukan tomato serta kemasakan tomato, menggunakan pembuat keputusan daripada Jaringan Neural yang juga menjadi objektif utama. Pendekatannya ialah untuk mengesan objek yang perlukan menggunakan sistem penglihatan yang dipasangkan pada sistem automasi selinder dan menghasilkan analisa imej. Ciri-ciri ini akan berfungsi sebagai masukan kepada jaringan neural, yang mana akan dilatih dengan satu set tomato masak yang telah dikenalpasti. Keluarannya ialah arahan

kepada lengan penuai bagi menghasilkan gerakan untuk penuaian. Penentuan kedudukan dilakukan dengan menukarkan jarak dalam unit pixel kepada jarak dalam unit metrik (mm) untuk imej tomato. Sebaliknya jarak kedalaman tomato (arah z) dilakukan dengan menggerakkan lengan penggerak sistem kearah kedudukan tomato yang telah dikira kedudukannya sehingga sensor objek mengesan kehadiran tomato. Perisian AWIsoft07 berkeupayaan mempamirkan pandangan penuai, dan memaparkan analisa imej yang diperolehi daripada pandangan penuai, memaparkan keluaran analisis berangka dan keluaran jaringan neural.

Sistem penuai slinder dengan tiga darjah kebebasan dengan penggenggam tomato yang rekabentuk khas dinamakan sebagai AWI2007 Robot Penuaian Tomato telah dibangunkan demi merealisasikan data daripada perisian AWIsoft07. Beberapa kalibrasi telah dilakukan untuk memastikan ketepatan AWI2007 Robot Penuaian Tomato. Perisian AWIsoft07 dan AWI2007 Robot Penuaian Tomato telah melalui beberapa ujian penuaian di bawah kesekitaran makmal. Keputusan penuaian menunjukkan kebolehan perisisan dan penuai. Sesungguhnya, AWI2007 Robot Penuaian Tomato berkeupayaan untuk mengenali kemasakan buah tomato dan bergerak kekedudukan penuaian secara pintar. Keadaan ini telah menghasilkan suatu penambahbaikan untuk sistem penuaian tomato berbanding dengan hasil dapatan sebelumnya. Kesimpulannya aplikasi jaringan neural berasakan penglihatan kamera telah berjaya dihasilkan sebagai kepintaran tiruan untuk sistem robot penuaian tomato.

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Sincere gratitude and appreciation is also addressed to my beloved wife, kids, family and friends for their full support, help, and encouragement in continuing my study.

I certify that a Thesis Examination Committee has met on 2 December 2008 to conduct the final examination of Aziz bin Mamat on his thesis entitled "Development of a Neural Network-Based Camera for Tomato Harvesting Robots" in accordance with Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A)106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of Supervisory Committee were as follows:

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Date: 9 April 2009

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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AZIZ BIN MAMAT

Date : 30 January 2009

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LIST OF ABBREVIATONS

θ	The threshold value
α	The learning rate.
$\delta_k(p)$	The error gradient at neuron k in the output layer at iteration p.
$\partial y_k\ (p)$	The output of neuron k in the output layer at iteration p.
$\partial x_k\ (p)$	The net weighted at neuron k in the output layer at iteration p
$\Delta w_{jk}(p)$	The output layer weight correction at hidden layer j.
2D	Two dimensions
3D	Three dimensions
ANN	Artificial neural network
CCD	Couple charge diode
CW	Clockwise
CCW	Counter clockwise
d	The camera distance (mm)
d.c.	Direct current
DOF	Degree of freedom
$e_k\ (p)$	The error of neuron k in the output layer at iteration p
Ec	Calibration error
Er	The percentage of error
GUI	Graphical User Interface
IGES	Improved gray-scale
MSE	Mean square of error
MT	Metric ton
n	The number of neuron input

NN	Neural network
P	The distance in pixels
PSD	Position-sensitive device
Q	The distance in millimeters (mm).
R^2	Coefficient of regression
R_{CCW}	The counter clockwise X axis angle of rotation in degrees
R_{CW}	The clockwise X axis angle of rotation in degrees
RGB	Red, Green and Blue color space
T_{CW}	The time given to activate the X axis motor in second for clockwise rotation.
T_{CCW}	The time given to activate the X axis motor in second for counter clockwise rotation.
T_{DW}	The downward time given to activate Y axis motor, in second.
T_{UW}	The upward time given to activate Y axis motor, in second.
TV	Television
UPM	Universiti Putra Malaysia
U.S.A	United State of America
USB	Universal serial bus
Volt	Voltage
w_i	The weight of input i
$w_{jk}(p)$	The output layer weight.at hidden layer j.
$w_{jk}\ (p + 1)$	The output layer updating weight at hidden layer j.
x_i	The value of input i
X	The net weighted input to the neuron
$y_{d.k}(p)$	The desired output of neuron k at iteration p.
$y_j(p)$	The output of neuron j in the hidden layer p

$y_k(p)$	The actual output of neuron k at iteration p
Y	The output of the neuron
Y_{DW}	The displacement distance in downward direction in millimeter
Y_{UW}	The displacement distance in upward direction in millimeter

CHAPTER 1

INTRODUCTION

1.1 Overview

Lycopersicum esculentum which is known as tomato was classified under fruity vegetables. Tomato was originated from South America and widely produced in the tropical environment. Cameron Highland was the main tomato production area in Malaysia, and for the low land tomato widely produced in Johor (MOA, 2006).

Consumption of the tomato in Malaysia can be categorized into fresh and process tomato. The process tomato mainly can be divided into tomato puree, tomato paste and concentrated tomato. Processed tomato also produced tomato sauce and ketchup. Ministry of Agriculture in Malaysia reported that in year 2001, Malaysia imported 8,588.59 metric ton (MT) (RM20,605,256) tomato puree, tomato paste and concentrated tomato, where as in 2002 (until April) Malaysia imported 2,248.52245 MT(RM5,183,535) (MOA, 2006). Malaysia also exported 12,295 MT fresh tomato in 2000 and stand 20th place world ranking for tomato exporter. Malaysia exported 7,517MT tomato sauce and ketchup which is 1% of the world market (MOA, 2006). The decrement in import and increment in export, indicate that the tomato production in Malaysia showed a positive indicator for expansion.

To produce tomato in a large volume needs a large area of land. The best tomato cultivation is on the high land area cultivated with the high land variety tomato. However the highland area is limited, therefore tomato production must be done in the low land area with the cultivation of the good variety lowland tomato. The

modern production techniques must be practiced with controlled environment. Under the green house production system, the possibility to apply the automation and robotic system become more relevant especially when the rising cost of labor and the difficulties to employ the labor for agricultural work.

Recently many researchers develop the robot in the way of fully autonomous and move like the human being. The vision system was developed to represent the human eyes by using capture device such as camera. The capture devices were used, ranging from an expensive video camera, couple charge diode (CCD) camera, digital camera, to the low-priced web camera. The different camera will give the different sensitivity and resolution. The sensitivity of the capture device also depends on the environment condition, especially to the light intensity. Normally the captured image especially when using web camera will displayed in the Red, Green and Blue (RGB) color space. The digital image processing is able to reduce the effect light intensity to the captured images. The digital image processing also can be applied to identify the pattern of the object in the image.

In the new era of the robot development, artificial intelligent becomes one of the most important tools to make robot becomes intelligent. The artificial intelligent is defined as "the study of the computations that make it possible to perceive, reason, and act", includes an expert systems, fuzzy logic and artificial neural network (Winston, 1993).

Traditionally, tomato harvesting was done manually by picking the fruit by hand or cut by knife or scissor. Traditional harvesting method is normally facing the

problems of labors and time consuming. Therefore the paradigm change needed to be done in this area. Mechanization or automation in the harvesting seems to be a solution for those problems. The physical characteristics of the tomato plant, such as soft and brittle stem are constraints to the mechanization application. The fruit itself is covered by soft layer skin. Consequently, the application of mechanization for harvesting tomato may damage the tomato stem and bruise the tomato fruit.

Therefore the best way to make the paradigm change is using automation in harvesting. The advantages of automation are

i) Tomato fruit will avoid from bruise during harvesting.

ii) The tomato plant will not be damaged during harvesting.

iii) The usage of labor will be reduced.

iv) The tomato is possible to be graded during harvesting.

v) The robot is capable of working non stop (due to the power supply life time).

Further more, there are several disadvantages for automation, such as higher initial capital needed and good technical knowledge to operate. The cost for maintenance is also high when using automation.

1.2 Problem Statements

The introduction of the robot in the bioproduction environments not only saves labor but will help raise productivity. The developments of the agriculture robots were raise according to the needs. For examples, an autonomous six-legged walking robot was developed to explore and sample in rugged for outdoor environments

(Hoffman, 1991). The three degree of freedom (DOF) agricultural harvester robot was designed to perform the oil palm harvesting (Bouketir, 1999). The agricultural harvester robot was equipped with CCD camera for red object identification and an algorithm was also developed in order to transfer two dimensional image plane to the base of the three dimensional coordinate frame. However no report was made on the intelligent robot component. The 'robot eye' system for agriculture robot to predict actual distance of the target object using videogrammetry technique and triangulation method was developed toward the intelligent robot (Mohd, 2002).

The evolution of the robot works under the greenhouse environment also grows in the similar way. The mushroom harvesting robot was developed by Reed et.al., (1995) to find the relation between detachment torque and cap diameter and the relation between torque and twist angle detachment. It was reported that an available torque of 200Nmm combined with a rotational angle of 180˚ should be necessary. Van et. al. (2006) reported on the de-leafing cucumber plant using an autonomous robot. In a number of cases one leaf was reported successfully removed. The vision system and manipulator control was reported perform relatively well (Van et. al., 2006; Van et. al., 2002).

The research on the strawberry harvesting robot was reported by Satou et. al, (1996), and the cherry tomato harvester robot (Fujiura et. al., 1990; Subrata et. al., 1995) were developed by researches. The robot was guided with machine vision (a 3-D vision sensor) and the harvesting algorithm. The end-effectors for the tomato harvesting robot also were developed by Monta et. al. (1998). The end-effectors with two parallel plate fingers and a suction pad was reported successfully harvest