UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF A VISION SYSTEM INTERFACE FOR THREE DEGREE OF FREEDOM AGRICULTURAL ROBOT

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By

BOUKETIR OMRANE

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This Work is Dedicated
to
My
Parents
Brothers and Sisters

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LIST OF ABREVIATIONS

2D	Two Dimensions
3D	Three Dimensions
CAD	Computer Aided Design
CCD	Charge Coupled Device
DB-16R	16 Channel Relay Output Board
D-H	Denavit and Hartenberg
DIO-64	64 Bit Digital input/output With Timer/Counter Board
DOF	Degree of Freedom
DOS	Disk Operating System
DSV	Directional Solenoid Valve
FDP	Forward Dynamics Problem
FFB	Free Fruit Bunch
HTLS	High Torque Low Speed
IBVS	Image-Based Visual Servoing
IDP	Inverse Dynamics Problem
I.K	Inverse Kinematics
L-E	Lagrange-Euler
MIL	Matrox Imaging Library
N-E	Newton-Euler
RAM	Random Access Memory
RGB	Red, Green and Blue
VML	Virtual Machine Language

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

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Chairman: Associate Professor Ir. Wan Ishak Wan Ismail, Ph.D.

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In this study, a vision system interfaced 3DOF agricultural harvester robot was designed, developed and tested. The robot was actuated by hydraulic power for heavy tasks such as picking and harvesting oil palm FFB. The design was based on the task of that robot, the type of actuators and on the overall size. Attention was given to the stability, portability and kinematic simplicity in relation to the hydraulic actuators. The derivation of the kinematic model was based on the Matrix Algebra for the forward kinematics, and the inverse kinematics problem was based on analytical formulation.

The D-H representation was used to carry out the coordinates of the end-effector as the function of the joint angles. The joint angles of the robot were computed as the function of the end-effector coordinates to achieve the inverse kinematic model. A mathematical model that related the joint angles and the actuators length was derived using geometric and trigonometric formulations.

A differential system was derived for the manipulator. This differential system represents the dynamic model, which describes relationships between robot motion and forces causing that motion. The Lagrange-Euler formulation with

the D-H representation was applied to formulate the differential system. The importance of the derivation of the kinematic model arises in the development of the control strategy. While the derivation of the dynamic model helps in real time simulation.

The robot was enhanced by a CCD camera as a vision sensor to recognise red object as a target. Red object was to exemplify the matured oil palm FFB. The recognition process was achieved by using C++ programming language enhanced by MIL functions. An algorithm based on empirical results was developed in order to convert the target coordinates from the image plane (pixel) into the robot plane (cm). The image plane is two-dimensional while the robot plane is three-dimensional. Thus at least one coordinate of the target in the robot plane should be known. An Interface program has been developed using Visual Basic5 to control and simulate 2D motion of the manipulator.

Through an interfacing card, the developed computer program controlled the manipulator according to the information provided by the camera about the recognised target. The control algorithm was based on the derived kinematic model and on the relationships between the joint angles of the robot and the lengths of the hydraulic cylinders. The control operation was successfully accomplished with an error of 1 to 5 cm in the positioning of the end-effector. This error was due to several factors such as the inaccurate manufacturing and assembly and the accuracy and calibration of the vision sensor.

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MEREKABENTUK DAN MEMBANGUNKAN SISTEM PENGLIHATAN ANTARAMUKA ROBOT PERTANIAN DENGAN TIGA DARAJAH KEBEBASAN

Oleh

BOUKETIR OMRANE

Jun 1999

Pengerusi: **Profesor Madya Ir. Wan Ishak Wan Ismail, Ph.D.**

Fakulti: **Kejureturaan**

Buat masa sekarang, robot pertanian 3DOF telah direkabentuk dan dibina. Robot ini digerakkan menggunakan kuasa hidraul bagi membuat kerja-kerja berat umpamanya memetik dan menuai tandan buah kelapa sawit. Rekabentuk ini diasaskan kepada beban yang ditanggung oleh robot, jenis penggerak dan saiz keseluruhan. Penumpuan diberi kepada kestabilan, kemudahalihan dan permindahan kinematik di dalam kawalan penggerak hidraul. Perolehan model kinematik adalah berasaskan matriks algebra untuk kinematik kehadapan, dan masalah kinematik pengunduran berasaskan formulasi analitikal.

Hasil pembentangan D-H telah digunakan untuk mendapatkan koordinat hujung lengan sebagai fungsi sambungan sudut. Sambungan sudut robot telah dikira sebagai fungsi koordinat hujung lengan untuk menghasilkan model kinematik pengunduran. Model matematik yang berhubungkait dengan sudut penyambungan dan panjang penggerak telah diperolehi menggunakan formulasi geometrik dan trigonometrik.

Sistem kebedaan telah diperolehi untuk pengolah. Sistem kebedaan ini mewakili model dinamik, yang menerangkan hubungan di antara pergerakan robot dan daya yang menyebabkan pergerakan. Formulasi Lagrange-Euler dengan pembentangan D-H telah digunapakai untuk menghasilkan sistem kebedaan. Kepentingan perolehan model kinematik telah dibangkitkan dalam pembangunan kawalan strategi, manakala perolehan model dinamik membantu di dalam simulasi masa sebenar.

Robot ini telah dilengkapkan dengan kamera CCD sebagai sensor deria penglihatan untuk mengenali objek berwarna merah yang dijadikan sasaran. Satu algorithma berasaskan keputusan eksprimen telah dihasilkan bagi menukar koordinat sasaran dari satah bayangan (pixel) kepada satah robot (cm). Satah bayangan ini adalah dua dimensi manakala satah robot adalah tiga dimensi. Maka, sekurang-kurangnya satu koordinat daripada sasaran dalam satah robot diketahui. Satu program antaramuka telah dihasilkan menggunakan "Visual Basic 5" untuk mengawal dan simulasi pergerakan 2D pengolah.

Melalui kad antaramuka, program komputer yang dibangunkan, mengawal pengolah mengikut maklumat yang diberi oleh kamera bagi mengenal sasaran. Kawalan algorithm yang diasaskan pada perolehan model kinematik dan hubungan diantara sudut penyambungan robot dan panjang silinder hidraul. Operasi kawalan telah berjaya dihasilkan dengan julat kesilapan 1-5 cm dalam penentuan kedudukan hujung lengan. Kesilapan ini adalah disebabkan beberapa faktor umpamanya pemasangan dari pengeluaran yang kurang tepat dan ketepatan serta tentu ukur sensor deria penglihatan.

CHAPTER I

INTRODUCTION

Mechanisation involves machines to do work, but operators are required to control them in detail and to instruct them. Thus mechanisation is a process of replacing human labours by machine labour. Automation is a qualitatively different process that eliminates both human labour and detailed human control; the automated machine controls itself throughout log sequences of tasks, i.e. the process is conducted automatically without human intervention to predetermined requirements, which may or may not have been extrinsically set by a human being.

The essential difference between mechanisation and automation is based on the presence of the closed-loop or feedback control in the latter, which enables the machine to control its performance at any moment by means of data supplied by the control unit that supervises the operation. The distinguishing characteristic of modern automation machine is that they contain some form of sensing organ, and a feedback path from the sensing organ to the actuators. The complete automation is a synthesis of five functions; sensing and recognition, program memory, process memory (or know-how), ability to make decision and physical control.

While the principle of feedback forms the basis of automation, its basis is the computer. Computers are composed of storing, processing and analysing masses of data supplied by sensing devices, via the closed-loop control system of the feedback mechanism, and of coming out decision-making on the basis of this intelligent activity. Automation also signifies the machine's capability of information processing and task execution with minimum or no human supervision. These capabilities include the aspects of perception, reasoning and learning, communication and task planing and execution. Robots are type of the automated machines. They are intelligent machines with generic mechanism where a mechanical manipulator might be programmed and controlled automatically to perform various repetitive tasks.

The earliest applications of the robots in industry were in material handling, spot welding in car manufacturing and spray painting. Robots were initially applied to jobs that were hot, heavy and hazardous such as die casting, forging and spot welding (McKerrow, 1991). The introduction of the robots into factories has already had a considerable impact on manufacturing process. The automobile industry has been largely responsible for the development of industrial robots. Traditional production lines were designed for one car model only, and had to be redesigned and rebuilt before a new model could be manufactured. Manual welding was subject to considerable variability because the spot welding guns were heavy and difficult to handle. A robot welding line can be changed from one car model to another simply by reprogramming the welding pattern performed by the robots. Consequently, it is possible to mix models on one line, and to customise models for particular order. Robots are also used in the nuclear industry for remote welding and pipe inspection in high-radiation areas. In agricultural sector, robots for crops transplanting and harvesting are in their experimental stage.

In the early 1980's, the push for industrial robots was driven by high cost of labour, regulatory and material. Today, similar concerns are facing the agricultural industry. The cost of fuel to drive agricultural machinery, the increasing regulatory burden of applying fertiliser and pesticide, shortage of labour and high cost of labour are forcing the agricultural industry to seriously evaluate the use of automation and robotics in agricultural tasks.

There are many problems to be solved, in the design and the development of an agricultural robot. The physical properties of agricultural products such as size, colour, shape, hardness, etc., vary even when they are of the same variety. The robots are required to work under various conditions such as natural illumination, hilly terrain and weather conditions. Therefore, agricultural robots have to be robust so that they can protect themselves from problems caused by water, dust and weather conditions

The main problems faced the agricultural sector are the shortage of labour, and inadequate technological input. In the early periods, the labour was plentiful and cheap. Nowadays, the situation is different; labour is becoming more expensive and short supply as a result with the competition of the industrial sector. This situation is more critical in the plantation crops such as oil palm, rubber and cocoa, where more workers are needed especially in the harvesting stages. It was reported that in oil palm plantations in Malaysia, the current labour is about 8 to 10 hectares per worker. However mechanisation operation can increase the labour usage up to 12 to 13 hectares per worker. Thus, mechanisation can help reduce demand for labour. It also helps increase productivity by between 100% to 200% (Jalani, 1998). Mechanisation on agricultural sector makes possible crop intensification.

Although many agricultural operations have been mechanised, there are still many treacherous, laborious and monotonous tasks that are not suited for human but require some humanlike intelligence to perform. This has led the research from the development of the mechanised machines to the development of automated machines (agricultural robots) that can perform these tasks easily and efficiently. The necessity of agricultural robots is seen in the following areas(Kondo and Ting., 1997):

- The availability of the farming workforce is decreasing at an alarming rate in many countries. Compared with many other industries, agriculture is less attractive to the younger generation, as indicated by recent trends. This means that the supply of human resources for farming will continue to decrease in the foreseeable future. The development of bioproduction robots, especially the kind of expert knowledge, can serve to preserve some farming expertise.
- The problem of labour shortage frequently results in rising labour costs, if the agricultural production is to continue.
- The market demand for product quality has become an important factor in bioproduction. Quality evaluation of products has relied mainly on human judgement. Although the human capability in perception and reasoning is still not fully replaceable by machines, the stability and uniformity of human judgement are known to be unreliable. A substantial amount of effort has been made in solving this perception problem by machines, which is an important feature of agricultural robots.

The sort of jobs involved in agricultural operations is not straightforward and many repetitive tasks are not exactly the same every time. In most cases several factors have to be considered such as weather, type and state of fruits, leaf colour and terrain. Because of these factors, agricultural robots must satisfy certain conditions to be able to operate efficiently. One of these conditions is to be able to detect its target (i.e. fruit) and identify it from many other objects. The use of sensors is the way to accomplish this task. The use of sensing technology to endow machines with a greater degree of intelligence in dealing with their environment is an active topic of research and development in the robotics field.

Conventionally, sensors are classified into a number of categories (Brady,1989). Internal state sensors; include potentiometers, position encoders tachometers and accelerometers. Contact sensors; include contact switches, touch sensors, forces sensors, proximity sensors and slip sensors. Touch sensors have low spatial resolution, limited dynamic range and are prone to wear and tear. Non-contact sensors; include ultrasound, active infrared rangers, radar and vision. Application-dependent sensors; include smoke alarms, temperature sensors, smell sensors and speech sensors.

Internal state sensors deal with the detection of variables such as arm joint position, which are used for robot control. The non-contact sensors deal with the detection of variables such as fruits or obstacles, and are used for robot guidance as well as for object identification and handling. The operations of internal sensors could be replaced by a software programming. Recently the vision sensor is the most common in external state functions.

Automation and robotics has been an increasing interest to robot designers in recent years, especially in the vision-based robots system. A vision device is usually mounted on the robot in order to guide the end-effector to the desired position and orientation through the computer vision or image processing. The goal of the robot vision research is to make the robot simulate the human visual perception by understanding and analysing real time image sequences.

Although much effort in industry have been invested to provide an automatic guidance for robot in very demanding environments, the goal of reliability remains elusive, especially with low cost system in unconstrained environment. CCD cameras are the most common in vision sensors. They have been used for a variety of tasks for many years, mainly in inspection. Their application in robot navigation has been less successful, because of the missing of the 3D notion in their output, and however provide less information about the object.

Objectives

The objectives of this study are:

- To design, fabricate a 3 DOF prototype hydraulically actuated agricultural robot and to derive its kinematic and dynamic models that allow to implement a suitable control approach.
- To develop a software interface between a CCD camera and the developed robot that can identify, and handle a red object as a fruit target.

CHAPTER II

LITERATURE REVIEW

Previous works concerning agricultural robot have been generally based on the prevalent development methods in industrial robots. The phases of development of robot such as the design of the manipulator and its end-effector, robot kinematics and dynamic methods, and robot control strategies are discussed in this chapter.

Robot Design

The number of degree of freedom (DOF) of the system determines how many independently driven and controlled axes are needed to move a body in a defined way in space. The mechanical design of a robot requires application of engineering expertise in a variety of areas such as machine design, mechanical and electrical engineering.

Traditionally, robot design has been based largely on the use of simple design specifications relating to the number of joints, size, load capacity, and speed. Robots have been designed not to perform specific tasks but to meet general performance criteria (Shimon, 1985). Manipulators, bearings, shafts, links and other structural elements are selected for strength and stiffness to achieve the mechanical accuracy requirement. The same applies for selecting motor size, gearing, bearing and shafts, links size and link type.

Early robots were designed with general motion capability in order to find the largest market if they could perform the widest variety of tasks (Shimon, 1985). This flexibility proved to be expensive in both cost and performance. Robots are now designed with a set of tasks in mind. Overall size, number of DOF and basic configuration are determined from task specifications to reach work envelope, and orientation requirements. However, the design of an agricultural robot is a complex task since in addition to the many closely related design parameters that must be determined, the design is highly affected by crop parameters, which are uncertain and loosely structured (Kondo and Ting, 1997).

Edan *et al.* (1994) presented a system engineering method to evaluate the performance of an agricultural robot by simulating and comparing different types of robots, number of arms, multiple arm configurations, workspace design and dynamic characteristics. Numerical simulation tools are developed to quantify measures of machine performance such as cycle time and percentage of successful cycles based on an extensive statistical analysis using measured fruit locations and simulated crop parameters. The methodology developed by Edan was applied to determine design parameters for a robotic melon harvester. Simulation results indicated that the Cartesian robot was faster than the cylindrical one for the melon-harvesting task. Activating two arms in tandem was the fastest configuration evaluated. Simulation provided an important tool for evaluating the multitude of design and crop parameters and for comparing alternatives in a timely manner prior to prototype construction.

Seiichi *et al.* (1995) designed and developed a cucumber-harvesting robot This robot consisted of visual sensor, manipulator, hand and travelling device. Cucumber fruits are usually shielded by leaves covering a large area, often making the fruits too difficult to be recognised. The mechanism of the manipulator was investigated so as to take harvesting configuration, which have high manipulatability. A 6 DOF manipulator was manufactured as a trial. This manipulator consisted of a prismatic joint capable of sliding along the trellis with five rotational joints capable of taking various configurations. The test results showed that to improve the manipulatability of the manipulator, it was necessary to increase both the angles of trellis and the sliding stroke. The hand of the robot was designed and tested based on the physical properties of the cucumber plant. It consisted of a gripper section and a detector-cutter. The gripper first griped about 3cm below the top end of the fruit with a force of 6N and then the detector-cutter section slid upward. At the same time, the detector plate raised while its contact with the fruit was kept and the displacement being read by a potentiometer to detect the boundary between the fruit and the peduncle. If this detection was successful, the peduncle would be cut with a force of 12N by the cutter that was installed right under the detector plate. The whole robot was mounted on a travelling device having four wheels in order to accomplish the task.

Monta *et al.* (1995) developed a harvesting robot that worked in the vineyard. This robot which consisted of a manipulator, a visual sensor, a travelling device and end-effectors was able to carry out several tasks by changing end-effectors. Four end-effectors for harvesting, berry thinning, spraying and bagging were made for this robot system. The harvesting end-effector which grasped and cut rachis was able to harvest bunches with no damage. The berry thinning end-effector that consisted of three parts identified the bunch shape. The spraying end-effector sprayed the target uniformly, and the bagging end-effector was able to put bags on growing bunches continuously one by one.

Kondo *et al.* (1996a) described a basic constitution of an agricultural robot taking a tomato harvesting robot as an example. The harvester consisted of a 7 DOF manipulator to cover the whole range of all the fruit positions. The end-effector, consisted of two fingers. Because several fruits were grown in a cluster touching one another, a suction pad was added to the two fingers to move to the fruit using a rack-and-pinion system to suck the fruit. The basic mechanism of the robot and the details of the robot components were developed based on the physical properties of the tomato plant and on the environmental conditions. A cherry tomato harvesting end-effector was also developed so that the robot could harvest not only normal size tomatoes but also cherry tomatoes by changing the end-effector to make it multi-purpose robot.

Reed *et al.* (1995) developed a harvesting mushroom robot. The harvesting operation was broken down into a set of tasks: mushrooms locating, sizing, selecting, picking, transferring, conveying, trimming and packing. The picking device was mounted on the end of the longitude robot manipulator axis. A compact, lazy tongs mechanism was used to vertically position the suction cup picking assembly. This assembly consisted of a silicone-rubber; a bellow type suction cup attached to a sliding hollow barrel. A special fitting allowed the assembly to be rotated via a cable actuated by a pneumatic cylinder. The suction was provided by a vacuum inducer that could be switched from sucking to blowing to ensure positive release of the mushroom after picking. The inducer was also equipped with a vacuum sensor (switch) that was used to detect when good contact had been made with the mushroom.

In 1997 Reed *et al.* developed a new generation of mushroom harvester which was designed to automatically locate, pick, trim and transfer mushrooms from floor mounted trays into small containers in a real growing hose. The harvesting system