UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF AN AUTONOMOUS SYSTEM FOR AGRICULTURAL TRACTOR

MUHAMAD SAUFI MOHD KASSIM.

FK 2004 33

DESIGN AND DEVELOPMENT OF AN AUTONOMOUS SYSTEM FOR AGRICULTURAL TRACTOR

By

MUHAMAD SAUFI MOHD KASSIM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

April 2004

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

DESIGN AND DEVELOPMENT OF AN AUTONOMOUS SYSTEM FOR AGRICULTURAL TRACTOR

By

MUHAMAD SAUFI MOHD KASSIM

April 2004

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

Faculty: Engineering

This study describes the design and modification of a tractor for automatic control. The automated system developed for the unmanned tractor was for the purpose of master/slave operation in the agricultural sector. In this study, an hydrostatic transmission of the Kubota tractor was selected as the research platform. Modifications were carried out in order to automate the manual control tractor. The automated system was capable to direct the tractor to the target location given by the user. The sensing system guides the tractor to move along the path determined by the controller based on the information from the sensors.

The automated system was developed by combining of electromechanical system, multi-sensor integration and control software. The electromechanical system (electro-hydraulic and electro-pneumatic) was used to control the gear, brake, steering and accelerator system. The integration of sensors (Ultrasonic sensor, range sensor, magnetic sensor, encoder and potentiometer) provided the surrounding information to the tractor controller. The controller consists of series I/O modules (ICP 17000) and

also pair of radio modem for data transmission. The graphical user interface software to control the automated system was developed using the Visual Basic.

The automated system developed for ignition, gear, brake, accelerator and steering systems can be control remotely through the use of Graphical User Interface (GUI). The GUI has features, which enable the user to monitor the tractor condition and movement of the tractor by referring to the *simulation layer.* The *simulation layer* consist of pre-determined field map, scaled at 1cm: 1m.The simulation movement of the tractor was configured to coordinate with the real tractor movement. The GUI also enables the user to use keyboard to control the tractor movement. The GUI has a capability to calculate the location of the given target location and plan the tractor movement to the target location and assist the tractor to avoid the obstacle in the tractor path.

Abstrak tesis yang di kemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

MEREKABENTUK DAN MEMBANGUNKAN SISTEM AUTONOMUS UNTUK TRAKTOR PERTANIAN

Oleh

MUHAMAD SAUFI MOHD KASSIM

April 2004

Pengerusi : Professor Ir.Wan Ishak Wan Ismail

Fakulti: Kejuruteraan.

Kajian ini berkaitan dengan rekabentuk dan ubahsuai traktor untuk tujuan kawalan automatik. Sistem automatik untuk kawalan tractor tanpa pemandu di bangunkan untuk tujuan operasi *tuan /hamba* (master/slave) dalam sector pertanian. Dalam kajian ini sebuah traktor Kubota transmisi hidrostatik di pilih untuk pelantar kajian. Beberapa pengubahsuaian telah di lakukan untuk tujuan mengawal traktor secara automatik. Sistem automatik ini berupaya untuk mengarahkan traktor lokasi sasaran yang di berikan oleh operator secara automatik. Sistem penderia yang di bangunkan memandu traktor bergerak di sepanjang laluannya yang telah di tentukan oleh alat kawalan. Laluan ini di tentukan berdasarkan maklumat yang di terima oleh alat kawalan dari alat-alat penderia.

Sistem kawalan automatik di bangunkan dengan mengabungkan sistem elektromekanikal, intergrasi pelbagai alat penderia dan juga perisian kawalan. Sistem elektromekanikal(elektrohaidraulik dan elektropneumatik) digunakan untuk mengawal sistem giar, sistem brek, sistem stering dan sistem pendikit. Integrasi anatara alat

penderia (penderia ultrasonic, penderia jarak, penderia magnetik, enkoder, dan potentiometer) memberikan maklumat keadaan sekeliling kepada alat kawalan. Alat kawalan mempunyai beberapa siri module I/O (ICP 17000) serta sepasang modem radio untuk transmisi data. Perisian antaramuka bergrafik (GUI) yang di gunakan untuk mengawal sistem automatik di bangun menggunakan perisian Visual Basic.

Sistem automatik yang di bangunkan untuk sistem pencucuhan, sistem gegancu,sistem brek, sistem pendikit dan sistem stering boleh di kawal dari jarak jauh melalui penggunaan GUI. Penggunaan GUI membolehkan operator untuk menyelia kondisi traktor dan menyelia pergerakan traktor dengan merujuk pada *paparan simulasi. Paparan simulasi* mengandungi peta yang telah di tentukur berskala 1cm : 1m. Pergerakan simulasi traktor telah di konfigurasi supaya selari dengan pergerakan traktor sebenar. GUI juga mempunyai kebolehan menentukan lokasi kawasan sasaran serta merancang pergerakan traktor ke kawasan sasaran serta membantu traktor untuk mengelak halangan dalam laluannya.

ACKNOWLEDGEMENTS

Praises and thanks belong only to Allah S.W.T for giving me the opportunity to work with the following wonderful people throughout the course of this study. They are:

Prof. Dr. Ir. Wan Ishak Wan Ismail, for his excellent supervision, continuous encouragement, and guidance. Numerous discussions were instrumental for the completion of this thesis. Thanks to the members of the supervisory committee, Dr.Abdul Rashid Mohamed Shariff, and Dr.Samsul Bahari Mohd Noor, for their comments, concern, advice and support throughout this work.

My deepest appreciation also goes to Mr. Zakiria Ismail, Mr.Razak, Mr. Abdul Rahman, Mohd Hudzari Hj. Razali, Rahimi, Khairul Nizam, Mohd Muzli and Wan Rizaludin, for their continuous and valuable help, especially during the design and fabrication phases. Thanks also are given to all who lend their help directly or indirectly.

Last but not least, I would like to express my gratitude and sincere appreciation to my family members, especially my mother Hajah Khadijah binti Hj Mat Arof, my brothers Abang Yee, Abang Leh, Abang Ash, Abg Mie and my sisters Kak Mah, Kak Nie, Kak Puziah and Kak Siti for their undying support and encouragement,

I certify that an Examination Committee met on 29th April 2004 to conduct the final examination of Muhamad Saufi bin Mohd Kassim on his Master of Science thesis entitled "Design and Development of an Autonomous System for Agricultural Tractor" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

AZMI DATO' HJ. YAHYA, Ph.D.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

WAN ISHAK WAN ISMAIL, Ph.D.
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ABDUL RASHID MOHAMED SHARIFF, Ph.D.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

SAMSUL BAHARI MOHD. NOOR, Ph.D.
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

GULAM RUSUL RAHMAT ALI, Ph.D.
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 22 JUL 2004

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

WAN ISHAK WAN ISMAIL, Ph. D.
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

ABDUL RASHID MOHAMED SHARIFF, Ph.D.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Members)

SAMSUL BAHARI MOHD NOOR, Ph.D.
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Members)

AINI IDERIS, Ph.D.
Professor/Dean
School of Graduate Studies
University Putra Malaysia

Date: 16 AUG 2004

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and nations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Univeriti Putra Malaysia or other institutions.

MUHAMAD SAUFI MOHD KASSIM

Date: 06/08/04

TABLE OF CONTENTS

		PAGE
ABSTRACT		ii
ABSTRAK		v
ACKNOWLEDGEMENT		vi
APPROVAL		vii
DECLARATION		ix
LIST OF TABLES		xiii
LIST OF FIGURES		xiv
CHAPTER		
1	**INTRODUCTION**	**1**
	1.1 Problem statement	3
	1.2 Motivation	4
	1.3 Research Background	6
	1.4 Objectives	7
2	**LITERATURES REVIEW**	**8**
	2.1 Autonomous Mobile Robot Systems	8
	2.2 Dante II Autonomous Mobile Robot for Volcano	9
	2.3 Wireless System for Mobile Robot	11
	2.4 Tele-autonomous Guidance for Mobile Robots	13
	2.5 Electrohydraulic Steering	15
	2.6 Steering Controller	16
	2.6.1 Remote Voice-based Steering Control	18
	2.7 Automated Harvester	19
	2.8 Semi-Autonomous Tractor for Spraying Operation.	20
	2.9 Mobile Robot Positioning	22
	2.9.1 Odometry	23
	2.9.2 Inertial Navigation	23
	2.9.3 Magnetic Compasses	23
	2.9.4 Active Beacons	24
	2.9.5 Global Positioning Systems	25
	2.9.6 Landmark Navigation	25
	2.9.7 Map-based Positioning	26
	2.10 Guidance Systems for Agricultural Vehicles	27
	2.10.1 Master/Slave Vehicle Guidance	28
	2.10.2 Remote Controlled Vehicle Guidance	28
	2.10.3 Dead Reckoning	29
	2.10.4 Machine Vision	30
	2.10.5 GPS-based Systems	30
	2.10.7 Obstacle Avoidance with Ultrasonic Sensors	30
	2.10.8 Object recognition with Ultrasonic sensors	31
	2.11 Transducers and Sensors	32

	2.11.1 Positioning Transducer	34
	2.11.2 Velocity Transducer.	34
	2.11.3 Distance Measuring Sensors.	35
	2.11.4 Ultrasonic Distance Meter	36
	2.11.5 Accelerometer and Gyroscope	37
	2.12 Navigation systems	38
	2.12.1 GPS (Global Positioning System)	38
	2.12.2 DGPS (Differential Global Positioning System)	39
	2.12.3 KGPS (Kinematic GPS)	40
	2.12.4 Local navigation system	40
	2.8 Path planning	41
3	**METHODOLOGY**	**42**
	3.1 Design and Fabrication	42
	3.1.1 Ignition system	42
	3.1.2 Automatic ignition system	43
	3.1.3 Manual ignition	44
	3.1.4 Gear System	44
	3.1.5 Accelerator	45
	3.1.6 Steering system	47
	3.1.7 Steering feedback system	51
	3.2 Obstacle detection system	52
	3.3 Sensing strategies	52
	3.4 Traveling distance	59
	3.5 Controller	60
	3.6 Software Development	64
	3.6.1 Graphical User Interface (GUI)	66
	3.6.2 Visual Basic Programming	68
	3.7 Sequence of Operations	73
4	**RESULT AND DISCUSSION**	**74**
	4.1 Electromechanical system	74
	4.1.1 Ignition System	74
	4.1.2 Gear System	76
	4.1.3 Accelerator System	77
	4.1.4 Brake System.	77
	4.1.5 Steering System	78
	4.2 Controller	80
	4.2.1 Radio Modem and ICP Modules	81
	4.3 Sensing Strategies	82
	4.4 Obstacle Detection System	83
	4.5 Motion Planning System	85
	4.6 Control software.	87

5 CONCLUSION AND RECOMMENDATION 89
5.1 Conclusion 89
5.2 Recommendations 90

REFERENCES 92
APPENDIX A 96
BIODATA OF THE AUTHOR 97

LIST OF TABLES

Table		Page
3.1	Steering Angle Relative to Tire Turning Angle	50
3.2	Front Sensors Logics and Obstacles Information	57
3.3	Rear Sensors Logics and Obstacles Information	58
3.4	ICPCON-7000 Series and Radio Modem	60
3.5	GUI Keyboard Character	67
3.6	Inputs and outputs Assigning of the ICP Modules	70
4.1	Open Circuit Voltage VS Tire Turning Position	79
4.2	Radio Modem configuration	81
4.3	The effects of Sensor Distance, X	84

LIST OF FIGURES

Figure		Page
2.1	Dante II Volcano Exploration Robot	10
2.2	Graphical user interface of Dante II	11
2.3	The Wireless System for mobile robots	13
2.4	The E/H Simulator	16
2.5	Steering Controller Configuration	17
2.6	The Demeter automated harvester	20
2.7	Semi-autonomous tractor spraying a grove	20
2.8	Human interface to fleet of tractors	21
2.9	Signal Flow Diagram for Automatic Vehicle Guidance System	27
2.10	Distance Measurements Using Global Positioning System	39
2.11	Error Correction in the DGPS With a Static Installed Reference receiver	40
3.1	Schematic Diagram for Ignition Circuit	43
3.2	Schematic Diagram for Gear system	44
3.3	Gear Position	45
3.4	Schematic Diagram For Accelerator system	46
3.5	Accelerator Mechanism	47
3.6	Steering System Diagram	48
3.7	Modified Steering System Diagram	48
3.8	Tire turning angle relative to steering turning angle	49
3.9	Steering angle	50
3.10	Voltage divider circuit	51

LIST OF FIGURES

Figure		Page
3.11	Sensors Arrangement	52
3.12	Obstacles Conditions (Front)	54
3.13	Obstacles Conditions (Rear)	55
3.14	Encoder attached at rear tire	59
3.15	Connection of the Electro Hydraulic Steering System	61
3.16	Schematic Diagram Output Signal of the Ignition System	61
3.17	Schematic Diagram Output Signal for the Shut off System	62
3.18	Schematic Diagram Input & Output Signals for the Gear and Brake System.	63
3.19	Schematic Diagram Output Signal for the Accelerator System	64
3.20	The Main Window of 7000 Utility	65
3.21	Select the item NAP7000X	66
3.22	GUI Flowchart	71
3.23	GUI Flowchart (continuation)	72
4.1	Ignition Coil	75
4.2	Shut Off Coil	75
4.3	Gear System and Pneumatic attachment	76
4.4	Accelerator System	77
4.5	Brake System	78
4.6	Rotary Potentiometer for the steering feedback system	79

LIST OF FIGURES

Figure		Page
4.7	PC-Based Control Block Diagram	80
4.8	Controller Box	82
4.9	Sensor Distance and Sensing Range	83
4.10	Schematics Diagram Motion Planning System	86
4.11	GUI to control the tractor movement	88
4.12	GUI for monitoring the tractor	88

CHAPTER 1

INTRODUCTION

In the past decade there has been considerable effort to develop autonomous robotic vehicles for random patrols, barrier assessment, intruder detection, reconnaissance and surveillance, building entry, target detection, building or terrain mapping, and explosive neutralization. Mobile robotic platform with the above capabilities will improve the ability to counter treats, limit risks to personnel, and reduce manpower requirements in hazardous environments.

In agricultural sector, the development of autonomous tractor concentrate on reducing working hour, avoiding hazardous work, tedious work and overcome the unskilled tractor operator. Agricultural vehicles are designed to perform various agricultural operations, and often operated on unprepared and changing terrain at relatively high speed. Human operators use a significant amount of intelligence to combine job functions, visual and audio cues, motion sensations, and experience to maneuver the vehicle. Long hours and repetition easily result in operator's fatigue, which in turn causes safety issues and decrease operation efficiency. Automatically guided vehicles will not fatigue, and can reduce operator's work intensity, resulting in enhanced efficiency, and increased operation safety (Zhang et al. 1999).

In the 21st century it is very important to develop the production technology required to decrease the cost of food production and to ensure a stable food supply. In advanced countries, the lack of labor and aging work force complicate the situation. To solve these problems, vehicle guidance system that can reduce operator's fatigue will play an important role. In particular, the vehicle systems provide more efficient work and reduction in costs (Noguchi, 1995).

Driving an agricultural tractor in field without overrunning crops is a skill and labor-intensive task. The adoption of new agricultural technologies, such as precision agricultural, makes the maneuvering even more difficult. Meanwhile, the shortage and aging work force in agricultural results in decrease in skilled operators. Therefore, the development of automated or autonomous agricultural tractors is considered to be of societal importance. The rapid progress in guidance sensor and computer technologies makes it possible and affordable automated or autonomous agricultural tractors (Zhang et al. 1999).

Studies on the robotization of agricultural vehicle have been conducted in recent years to achieve the following objectives (Yukumoto, 1995).

1. Labor-saving through completely unmanned operations
2. High-precision work superior to human work, and
3. Improvement of safety and amenity by eliminating operator intervention

Subsequently, new working methods will be developed in response to robotization of agricultural vehicles and the following benefits are anticipated. (Yukumoto, 1990)

1. Single operator can manage and operate many vehicles concurrently.
2. Through continuous day and night work, a small machine can cover a large area and solve problems such as soil compaction, and
3. The ability to detect vehicle positions will enable to obtain information on yield and soil conditions of each part of the field and to execute precision farming.

1.1 Problem statement

In the farming sector of Malaysia, though the use of machines provides immense help to farmers, these machines require highly trained operators to handle. As time goes by, most of the operators of these machines have aged. And with the younger generation's lack of interest, solutions like foreign labors from neighboring countries have to be taken in to fill the reducing number of operators. Most of these labors are half trained labors of a particular field. Because of that, a substantial amount of time is required to train them to perform related work. As a result, high volume of cash flowing out and the production and maintenance costs will rise up.

The mechanization system available nowadays is very reliant on manpower. These use of machines requires work on areas that threatens the safety and health of the labor. With the rise of technology, various new technologies are introduced to the agricultural industry. An example would be the use of GIS (Geographical Information System) and GPS (Global Positioning System). Mechanization systems available nowadays need to be adapted to enable the use of these technologies. With the availability of unmanned tractors that are controlled with computers, hopefully the lack of expert labors will be resolved. These tractors make minimal monitoring possible without the operator even stepping on the farm. A result would be the reduction on the reliance of foreign workers, less accidents and health threats. This will directly reduce the cost of operation. The system is also able to increase the work done on farms by operating around the clock using automatic monitoring with computers. Hopefully this system has the potential to attract the interest of intellectual people to contribute and invest in the agricultural sector. If this is possible, then the agricultural sector has the potential to rise up on par with the rise of technological advancements in the information technology age.

1.2 Motivation

Mechanization is a very important input in agricultural operations. Automation is one of the important components in the mechanization. Tractor is the most popular machine among the farmers. Until today tractor had been used to do various kind agricultural operations. The purpose of an automated control tractor were:

- To reduce the farmers burden in operating the tractor. For various kind of agricultural operation required a skilled operator. The automated tractor can be operated by the unskilled operator with minimum supervision.

- The automated tractor can also be programmed to work over the normal working hour of the farmer
- In the precision farming practices, an automated tractor is one of the important components. The automated tractor can be used to collect and store various kinds of data that is required for the various agricultural operations started from land preparation until the harvesting operation

The idea of researching was spawned right after following the advancements of technologies used in agriculture especially in the use of automated tractors in countries like Japan and the US. This technology is not available in Malaysia. The technology that is being brought up in Japan and US are based on the agricultural needs of their respective country. This research currently done has also taken into account the agricultural needs in Malaysia because likewise, many factors differ between Malaysia, Japan and US.

Only fellow countrymen will know the exact needs of their own country. This unmanned tractor is constructed according to the compatibility with the farm, crops and also the climate in Malaysia. This research uses a big part of technology that is easily available in Malaysia. Though there are parts and equipment that are taken from overseas, this act allows the use of new technology in Malaysia. This research is not only used to broaden the use of new technology in agriculture, but also to open roads to Malaysians on the vast use of technology in various areas and sectors especially in the agricultural sector.

1.3 Research Background

Most of the autonomous tractor research, concentrate on field operation such as tilling, spraying, and harvesting. In this research the tractor is going to be design and modify as a traveling device for FFB harvesting robot arm. The task of the autonomous tractor to be studied is to carry and automate the equipments needed for harvesting operation. In completing the task the tractor should be able to recognize the obstacle, and planned the path to avoid the obstacles by taking the shortest path to the target.

The tractor will be equipped with the mechanical actuator, computer, electric and electronic instrumentations. Modification will be carried out on the tractor for unmanned control purposes. The mechanical actuators will be installed to replace the human tasks in controlling the steering, accelerator, gear and brake. The electrical motor will be use to control the accelerator pedal.

Sensors and transducers play an important role in obtaining the information about its environment; the current state of operation of the actuators, the tractor's turning angle, traveling distance, obstacles location and etc. Limit switches and proximity sensors are used to limit the movement of the hydraulic actuator. Photoelectric sensor will be used to determine the rotation of the electrical motor.

To determine the turning angle a potentiometer was used and a sonar sensor was used to determine the obstacle position and distance.

A radio modem was used for signals transfer from far distances. The radio modem is used to monitor the tractor from distance. The modem communicates via RS 232 port. While a computer system will control the whole operation assist by the user interface software. Through the GUI user can be able to control the tractor movement and monitor the data from the sensor on the tractor. There are two types of control movements, remote mode and auto mode. In the remote mode the user control the movement of the tractor by using the computer keyboard, while in the auto mode the user need to give the coordinate of the target location and activate the 'Auto" command button in the GUI. The movement of the tractor can be simulates on the pre-determined map in the GUI. The software will be developed using visual basic programming.

1.4 Objectives

The main objective of this project is to develop the control system for a tractor as an autonomous platform for agricultural operation in the plantation environment.

The specific objectives of this project are:

1. To design the vehicle motion planning system.
2. To design the obstacles detection and avoiding system.
3. To develop the electromechanical and control system for the autonomous operations.

CHAPTER 2

LITERATURE REVIEW

2.1 Autonomous Mobile Robot Systems

Autonomous mobile robot systems are vehicles, which are capable of performing independent movements and operations without following guidance systems or being steered by a remote control. An autonomous vehicle must be able to determine a collision free path from a start position to a goal position, with known or also potential unknown obstacles into consideration. With the help of its sensor technology, the robot must be capable to record information about it's own position and the structure of it's environment. There are often uncertainties with regard to the position and the identity of objects, which the autonomous vehicle has to handle during its main task, reaching its goal without collision. One advantage of autonomous vehicle compared to robot manipulators is the fact that no such a high positioning accuracy is required.

Spandl (1991). distinguishes several job steps of a mobile robot: the *vehicle control*, the *sensory mechanism*, the *navigation*, the *application of suitable sensor strategies* and the *path planning*. The *vehicle control* is engaged with the movement of the vehicle along a given trajectory with known kinematic and dynamic boundary conditions, whereby the main point is the interpolation of the trajectory and the drive (control) of the motors.