

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Autonomous Control of a Humanoid Soccer Robot:  
Development of Tools and Strategies  
using Colour Vision**

*A thesis presented in partial fulfilment of the  
requirements for a degree of*

Master of Engineering

Mechatronics

at

Massey University,

Albany, New Zealand.

Baden Rielly

2007

---

## Masters Abstract

Humanoid robots research has been an ongoing area of development for researchers due to the benefits that humanoid robots present, whether for entertainment or industrial purposes because of their ability to move around in a human environment, mimic human movement and being aesthetically pleasing. The RoboCup is a competition designed to further the development of robotics, with the humanoid league being the forefront of the competition.

A design for the robot platform to compete at an international level in the RoboCup competition will be developed. Along with the platform, tools are created to allow the robot to function autonomously, effectively and efficiently in this environment, primarily using colour vision as its main sensory input.

By using a 'point and follow' approach to the robot control a simplistic A.I. was formed which enables the robot to complete the basic functionality of a striker of the ball. Mathematical models are then presented for the comparison of stereoscopic versus monoscopic vision, with the expansion on why monoscopic vision was chosen, due to the environment of the competition being known. A monoscopic depth perception mathematical model and algorithm is then developed, along with a ball trajectory algorithm to allow the robot to calculate a moving balls trajectory and react according to its motion path.

Finally through analysis of the implementation of the constructed tools for the chosen platform, details on their effectiveness and their drawbacks are discussed.

---

## Acknowledgments

I would like to thank all the people who have helped me throughout this project. I would like to thank my partner Dina for all her continual encouragement and assistance, which has seen me through all the good and bad times. Next I would like to thank my family for their support, and a big thanks to my mother, Rio for helping me proofread my thesis.

To the Massey University staff of the engineering department and my supervisors Prof. Olaf Diegel, Dr Johan Potgieter, who I would like to thank for their help and guidance throughout my masters, and for giving me this opportunity.

Finally I would like to thank all my friends and all the postgraduate students, Lim Kang for working on the project with me, Matthew Read, Courtney DeLautour and Jonathan Zyzalo for all your contributions, and all the others that have worked alongside me, helped me to complete my project, and for all the good times had.

---

## Contents

<u>Masters Abstract</u> .....	I
<u>Acknowledgments</u> .....	II
<u>List of figures</u> .....	VI
<u>List of tables</u> .....	VIII
<b><u>Chapter 1: Introduction</u></b> .....	<b>1</b>
1.1: Project Background and Objectives .....	1
1.2: Research Publications .....	2
1.3: Thesis Layout .....	3
<b><u>Chapter 2: Literature Review</u></b> .....	<b>4</b>
2.1: Autonomy in Robotics .....	4
2.2: Robot Localisation .....	4
2.3: RoboCup .....	5
2.4: Existing Humanoid Robots .....	8
2.5: Existing RoboCup Systems .....	10
2.6: Hardware Requirements .....	15
2.6.1: Research Platform .....	15
2.6.2: Digital Compass .....	16
2.7: Vision Systems .....	18
2.7.1: Colour Vision .....	18
2.7.2: Omni-directional .....	18
2.7.3: Wide Angle Lens .....	19
2.7.4: Stereo Vision .....	19
2.7.5: Developed Vision Boards .....	20
2.8: Control Board .....	24
2.8.1: Robot Controller board .....	25
2.8.2: Microcontroller .....	25
2.8.3: PDA .....	26
2.8.4: PC - 104 .....	26
<b><u>Chapter 3: Development of the Mechatronic System</u></b> .....	<b>28</b>
3.1: Vision System Development .....	28

---

3.1.1:	Monoscopic Vision .....	28
3.1.2:	Stereo Vision.....	33
3.1.3:	Monoscopic versus Stereo Vision.....	35
3.1.4:	Camera .....	36
3.2:	Implementation of Autonomy through Vision.....	38
3.2.1:	Robot Motions.....	39
3.3:	Device Integration and Interfacing.....	41
3.3.1:	Device Communication.....	41
3.3.2:	Power Requirements .....	42
3.4:	Robot Mechanical Design .....	44
<b>Chapter 4:</b>	<b><u>Humanoid Robot A.I. ....</u></b>	<b>51</b>
4.1:	Basic A.I Using Point and Follow Routine.....	51
4.2:	Tasks .....	52
4.3:	Order of Events .....	52
4.4:	Software Routines .....	55
4.4.1:	Search.....	55
4.4.1.1:	Field of view .....	56
4.4.2:	Get to ball.....	58
4.4.3:	Position to ball .....	59
4.4.4:	Shoot Goal.....	61
4.4.5:	Special Cases.....	62
<b>Chapter 5:</b>	<b><u>Ball Path Planning .....</u></b>	<b>63</b>
5.1:	Distance.....	63
5.2:	Direction.....	68
5.3:	Distance implementation into software.....	69
5.4:	Trajectory Calculation.....	70
5.5:	Implementation into A.I.....	73
5.6:	Simple Goal Localization.....	82
<b>Chapter 6:</b>	<b><u>Testing &amp; Results .....</u></b>	<b>83</b>
6.1:	Testing and analysis of the point and follow routine .....	83
6.2:	Analysis of distance and direction calculations .....	88

---

---

6.2.1: Stationary Robot .....	88
6.2.2: Moving robot.....	90
6.3: Examination of the estimated ball trajectory .....	94
6.4: Implementation of the Path Planning Algorithms.....	100
<b><u>Chapter 7: Conclusion &amp; Future Work.....</u></b>	<b>104</b>
<b><u>Glossary.....</u></b>	<b>107</b>
<b><u>References .....</u></b>	<b>109</b>
<b><u>Appendix A (How to operate the robot).....</u></b>	<b>117</b>
<b><u>Appendix B (Result Spreadsheets) .....</u></b>	<b>120</b>
<b><u>Appendix C (CODE).....</u></b>	<b>144</b>
<b><u>Appendix D (Data Sheets &amp; Publications).....</u></b>	<b>203</b>

---

### List of figures

Figure 1:	Soccer field [Behnke].....	6
Figure 2:	Humanoid robot body plan [Behnke].....	7
Figure 3:	Robosapien vision through wide-angle lens [Behnke et.al. 1].....	12
Figure 4:	Pirkus – R Type 01 DX [IBee].....	16
Figure 5:	CMP03 electronic compass module [CMPS03] .....	17
Figure 6:	CMUcam2 [Rowe].....	22
Figure 7:	Controller Board [Rowe].....	24
Figure 8:	Calculating the robot’s distance for the ball. ....	29
Figure 9:	Resolution error of monoscopic vision .....	30
Figure 10:	Distance error of monoscopic vision .....	31
Figure 11:	Graphs of different pixel errors for various resolutions (graph (d) is the vertical error of the CMUcam2 resolution with 33 <sup>0</sup> view angle).....	32
Figure 12:	Stereo vision depth perception calculation .....	34
Figure 13:	New neck joint initial design .....	44
Figure 14:	SolidWorks model of the main body of head joint .....	45
Figure 15:	Servos attached to main body of head.....	46
Figure 16:	SolidWorks model of the inner head joint and assembly.....	47
Figure 17:	Section view of head assembly .....	48
Figure 18:	New neck joint final design.....	49
Figure 19:	Final design of robot .....	50
Figure 20:	Initial Truth Table for Robot A.I.....	54
Figure 21:	Vertical Search .....	57
Figure 22:	Flow diagram of flags .....	60
Figure 23:	Actual distance of ball from robot .....	64
Figure 24:	Comparison of distance calculation (a) 80mm ball (b) 40mm ball.....	67
Figure 25:	GUI for robot control .....	69
Figure 26:	Ball travelling away from the robot .....	71
Figure 27:	Ball travelling towards the robot.....	72
Figure 28:	Error in trajectory calculations from monoscopic system .....	74



---

Figure 29:	x and y co-ordinates of the ball .....	75
Figure 30:	Line of best fit .....	77
Figure 31:	Transition from ball oncoming to travelling away from the robot .....	79
Figure 32:	Updated flow diagram of robot A.I.....	81
Figure 33:	Robot Approaching the ball .....	84
Figure 34:	Searching for goal and positioning around ball .....	85
Figure 35:	Final positioning for shot and kick at goal.....	86
Figure 36:	Robot shooting goal .....	87
Figure 37:	Comparison of distance calculations while robot stationary.....	89
Figure 38:	(a) Real-time plot of average distance, .....	90
	(b) Real-time plot of corrected average distance .....	90
Figure 39:	Comparison of distance calculations while robot walking .....	91
Figure 40:	Real-time plot of average distance while walking .....	92
Figure 41:	Graph of direction of head while robot walking .....	93
Figure 42:	Slope of balls trajectory while ball travelling along y axis.....	96
Figure 43:	Graph of y intercepts while ball travelling along the x axis .....	97
Figure 44:	Slope of ball when travelling across the 2 axes .....	98
Figure 45:	Graph of x intercepts of balls trajectories .....	99
Figure 46:	Graph of y intercepts of the balls trajectories .....	99

---

**List of tables**

Table 1:	Soccer field in cm. [Behnke].....	6
Table 2:	Limitations in vertical search .....	57
Table 3:	Servo Parameters.....	83
Table 4:	Ball Transition values .....	101

---

## Chapter 1: Introduction

### 1.1: Project Background and Objectives

Robot soccer is a new area of research to further development in robotics. The humanoid leagues are a new area of advancement in the game, with the objective to have a fully autonomous humanoid robot team capable of competing with the world's best by 2050 [Behnke et.al. 3][Burkhard et.al.][Kitano et.al.]. The development of a humanoid soccer robot team is a goal of the Mechatronics department at Massey University.

The appeal of humanoid robotics is that a humanoid robot can be used to carry out tedious and dangerous tasks that a human would normally be required to perform. Industries like construction could use the robots to perform tasks that would be considered life threatening [Inoue et.al.]. Humanoids could also be used in the entertainment industry to serve humans with their close resemblance to humans making them more readily accepted [Bekey].

The first objective of this project is the development of a soccer robot platform using off the shelf components, which will be able to compete in a robot soccer competition. The robot platform, and external devices, will have to be researched, and the appropriate devices chosen.

The control of the robot through vision will be the main focus of this project. A set of tools will be developed using colour vision that will aid the A.I. (Artificial Intelligence) of the final autonomous robot design.

---

The first tool will be a basic A.I. based on a point and follow routine. The aim is to use the camera as a pointer for the body of the robot to follow. Through this routine's implementation it is the goal to have a robot that has the basic cognitive ability to perform the required tasks to score a goal in a game of soccer, therefore enabling the robot to function autonomously.

The second tool that will be developed is a monoscopic depth perception algorithm. This added depth perception will not only allow the robot to predict the distance from the robot that an object is located, but allow subsequent calculations to be performed which will enable the robot to determine the trajectory of the ball's travel when in motion. The new information received by calculating the ball's trajectory will enable improvements in the overall A.I. of the robot.

## **1.2: Research Publications**

### *Refereed Conference Proceedings*

- B.J. Rielly, O. Diegel, C.L. Kang, M.J. Read, J.R. Zyzalo, J. Potgieter, W.L. Xu, "A Mechatronics Approach to Autonomous Control of a Humanoid Robot", 13<sup>th</sup> ENZCon, University of Canterbury, Christchurch, New Zealand, November, 2006.
- C.L. Kang, O. Diegel, B.J. Rielly, M.J. Read, J.R. Zyzalo, J. Potgieter, W.L. Xu, "Humanoid Biped Robots: Walking and Balancing using Natural Dynamics, ZMP, and Gyroscopic Sensors", 13<sup>th</sup> ENZCon, University of Canterbury, Christchurch, New Zealand, November, 2006.

---

### **1.3: Thesis Layout**

Chapter 2 will introduce robot soccer the RoboCup in particular, along with its requirements, and regulations. It will give provide background on humanoid robots that are being developed for the RoboCup and for other applications in the real world. Finally it will discuss the equipment that will be used for the robot platform being developed for this application.

Chapter 3 will go into the mechatronic systems produced and go over the choice between monoscopic and stereoscopic vision for this project. Chapter 4 outlines the distance and direction calculations that are used and leads on to trajectory calculations in chapter 5.

Chapter 6 discusses the results that were achieved through this project and finally chapter 7 outlines the future work presented by the project and the conclusions reached.