

# **BRITISH THESIS**

Supplied by

**THE BRITISH LIBRARY**

**DOCUMENT SUPPLY CENTRE**

Boston Spa, Wetherby

West Yorkshire, United Kingdom

LS23 7BQ

**REPRODUCED  
FROM THE  
BEST  
AVAILABLE  
COPY**

**DB5749-86**

**VOL I**

**PT**

Attention is drawn to the fact that the copyright of this thesis rests with its author.

This copy of the thesis has been supplied on condition that anyone who consults it is understood to recognise that its copyright rests with its author and that no information derived from it may be published without the author's prior written consent.

IMAGE PROCESSING FOR ROBOTIC MANIPULATION.

Visual Detection, Recognition and Orientation Of Objects  
For Robotic Manipulation Using Microprocessor Control.

Volume One Of Two.

Andrew Mark DEAN.

Doctor Of Philosophy.

University Of Bradford.

Postgraduate School Of Information Systems Engineering.

Studies in

1985.

## CONTENTS VOLUME ONE

	Page Number
1.0 Summary.	1
2.0 Introduction.	4
2.1 Industrial Robotics.	6
2.2 Vision And Sensory Feedback.	12
2.3 Social Considerations.	13
2.4 S.E.R.C Robotic Initiative.	15
3.0 State Of The Art Robotics.	18
3.1 Mechanical Systems.	18
3.1.1 Movement Types.	19
3.1.2 Power Supplies.	22
3.1.3 Other Mechanical Parts.	27
3.2 Control Systems.	28
3.2.1 Servo Or Non-Servo.	28
3.2.2 Types Of Motion For The Servo Robot.	29
3.2.3 Robotic Software And Languages.	31
3.3 Robot Systems And Their Applications.	32
3.3.1 Desirable Features For Robots.	32
3.3.2 Robotic Applications.	33
3.3.3 Currently Available Robotic Systems.	37
3.4 Sensory Systems.	38

	Page Number
3.4.1 Types Of Sensors.	38
3.4.2 Currently Available Vision Systems.	42
3.4.3 Current Applications Of Vision Systems.	44
4.0 Terms Of Reference - A Design Study.	47
5.0 System Overview and Choice of Direction.	50
5.1 Pattern Recognition Methods.	50
5.1.1 Template Matching Approach.	51
5.1.2 Decision Theoretic or Discriminant Approach.	53
5.1.3 Structural Syntactic Approach.	54
5.1.4 Summary Of Available Recognition Methods.	55
5.1.5 Dimensional And Colour Information.	56
5.1.6 Component Presentation.	58
5.2 Image Enhancement Techniques.	59
5.3 Pixel And Grey Level Density.	62
5.4 Robot Vision Inputting Devices.	66
5.5 Optical and Illumination Considerations.	68
5.6 CPU Hardware and Software Considerations.	70
5.6.1 Central Processing Unit.	70
5.6.2 Software Choice.	72
5.6.3 Choice Of Data Acquisition Method.	72
5.7 Component Feature Extraction.	76
5.8 Choice Of Direction At Project Start.	78

# Page Number

6.0	System Hardware.	80
6.1	System Hardware Overview.	80
6.2	CCTV Camera Data and Timing Control Circuits.	85
6.2.1	Camera Aspect Ratio and Clock Frequency.	88
6.2.2	Clock Generation Circuits.	93
6.2.3	Video Signal Sampling and Quantization.	93
6.2.4	DMA and Data Latch Timing.	96
6.3	Direct Memory Access To CPU Interface.	99
6.3.1	DMA to CPU Asynchronous Interface Operation.	101
6.3.2	DMA to CPU Bus Arbitration Interface.	105
6.4	Graphics Display Card.	109
6.4.1	Graphics Card Clock and Control Signals.	111
6.4.2	Graphics Address, Multiplexing and Monitor.	117
6.4.3	Graphics RAM and Data BUS Latch Control.	120
7.0	Software Overview.	123
7.1	Assembly Language Overview.	124
7.2	The Software Development Environment.	126
7.2.1	The Exormacs Development System.	128
7.2.2	The Exormacs Operating System - Versados.	130
7.2.3	The MC68000 CRT Editor 'E'.	131
7.2.4	The MC68000 Structured Assembler.	132
7.2.5	The MC68000 Linkage Editor.	133
7.2.6	Symbolic Debugger 'Symbug'.	134
7.2.7	The MEX68KDM Design Module and Macsbug.	135



Page Number

7.3	Assembly Language Routines.	138
7.3.1	Assembly Language Arrays.	139
7.3.2	Assembly Language Control Routine.	150
7.3.3	Inputting An Image To The Picture Store.	153
7.3.4	Edge Detection And Data Reduction.	162
7.3.5	Chain Encoding Of Components.	168
7.3.6	Calculation Of Basic Parameters.	175
7.3.7	Parameters Available From Component Holes.	185
7.3.8	Maximum And Minimum Radius Calculations.	197
7.3.9	Calculation of Circle Model Data.	205
7.3.10	Recognition, Position and Orientation.	211
7.3.11	Location Of The Largest Unrecognised Object.	230
7.3.12	Robot Communications Link.	233
7.3.13	Picture Store Change Routines.	238
7.3.14	Reconstructing the Images in the Store.	240
7.3.15	Midlectron Graphics Card Software.	243
7.3.16	Save/Recall of Learnt List to Hard Disc.	253
7.3.17	Timing Of Routines And Sub-Routines.	261
7.3.18	Sub-Routines Square Root And Angle.	265
7.3.19	High Speed Graphics Card Software.	277
7.3.20	General Sub-Routines.	279



## CONTENTS VOLUME TWO

	Page Number
8.0 Pascal Software Overview.	282
8.1 Pascal Arrays And Flags.	282
8.2 Pascal Development Environment.	290
8.3 The Pascal 'GUIDE' System.	292
8.3.1 Start Up And Top Level Menu Selection.	293
8.3.2 Learn Phase Menu.	295
8.3.3 Run Component Recognition Menu.	307
8.3.4 Basic Recognition Menu.	309
8.3.5 Parameter Calculation Menu.	311
8.3.6 Image Printing Menu.	312
8.4 Pascal Libraries.	316
8.4.1 Input/Output Runtime For The KDM System.	316
8.4.2 Initialisation Runtime For The KDM System.	324
8.4.3 User assembly Library Routines.	325
9.0 Testing And Timing.	328
10.0 Conclusions.	347
10.1 Achievement Of Objectives.	347
10.2 Limitations And Possible Future Development.	351
10.3 Robotics The future.	353

## APPENDICES

	Page Number
Appendix 1 Printed Circuit Board Layouts.	356
Appendix 2 Software Link Listing.	360
Appendix 3 Master Vision Assembly Software Listing.	367
Appendix 4 Graphics Card Assembly Software Listing.	446
Appendix 5 Master Vision Pascal Software Listing.	467
Appendix 6 Pascal KDM Runtime Library.	500
Appendix 7 Pascal User's Runtime Library.	509
References.	520
Acknowledgments.	529

LIST OF PLATES

Plate 1	Linear Robot Schematic and Photograph.	20
Plate 2	Rotary Robot Schematic and Photograph.	21
Plate 3	Combination Robot Photograph.	23
Plate 4	Vision System Test Rig and Monitors.	82
Plate 5	Direct Memory Access Printed Circuit Board.	84
Plate 6	Graphics Printed Circuit Board.	86
Plate 7	KDM Card Printed Circuit Board.	87
Plate 8	Vision System Test Rig and Components.	330
Plate 9	Test Components Input to Picture Store.	331
Plate 10	Test Components With Edges Traced.	333
Plate 11	Test Components Unchained and Labelled.	334
Plate 12	Test Components Numerical Data Displayed.	335

LIST OF PLATES

Plate 1	Linear Robot Schematic and Photograph.	20
Plate 2	Rotary Robot Schematic and Photograph.	21
Plate 3	Combination Robot Photograph.	23
Plate 4	Vision System Test Rig and Monitors.	82
Plate 5	Direct Memory Access Printed Circuit Board.	84
Plate 6	Graphics Printed Circuit Board.	86
Plate 7	KDM Card Printed Circuit Board.	87
Plate 8	Vision System Test Rig and Components.	330
Plate 9	Test Components Input to Picture Store.	331
Plate 10	Test Components With Edges Traced.	333
Plate 11	Test Components Unchained and Labelled.	334
Plate 12	Test Components Numerical Data Displayed.	335

### 1.0 Summary.

With the large increase in small batch production and the need for greater productivity and reduced costs, automation is taking over. Dedicated automation, such as is used on large production lines, is unable to cope with quick product changes hence the use of robots is increasing. At the moment these reprogrammable assembly devices have little intelligence and little or no sensing capabilities. If robotics is to expand into other production areas, the robots will require complex and intelligent sensors. It is for this need that the vision system developed in this thesis evolved.

There are many sensing systems used by man and machine of which vision is possibly the most useful, computer vision systems have been in existence for some years. The requirements of a computer vision system for robots are fundamentally different from those systems in existence, which have large computation times. A robot vision system must recognise and provide all the data required by the robot in a very short time, typically one second or less. This requirement was therefore set as one of the main design criteria. Other design criteria included object identification, calculation of object position and orientation, easy interfacing to any industrial robot and ease of operation. It was also felt that if vision was to become common place on industrial robots the cost should be kept low, less than £2000.

The methods of pattern recognition, grey level density, pixel array size, colour techniques and hardware and software filtering techniques were studied. From the design criteria specified and the recognition methods available, the decision theoretic approach was adopted as

other methods required lengthy recognition times or large memory storage. An array size of 256 pixels square at one grey level with as little image enhancement as possible was selected for the same reasons. With the recognition approach adopted the hardware and software was designed.

The hardware was designed round a Motorola direct-memory-access processor, transferring the image data from a closed-circuit television camera directly to memory. A Motorola state-of-the-art 16-bit MC68000 central-processing-unit then reduces and manipulates the data for recognition to occur. The MC68000 with its associated memory, interfacing, communication and timing circuitry are located on a Motorola KDM single board computer. Separate cards are used for the direct-memory-access, graphics and camera timing systems. The graphics unit displays components, data and results during the recognition phase.

The software is in two main sections, control is carried out by a Pascal master program, while the high speed recognition algorithms are performed by program segments written in MC68000 structured assembly language. The Pascal master section sets up and supervises all arrays and stacks, it also communicates with the user via a 'GUIDE' system during the teach phase. The teach phase is responsible for selecting the recognition models to be used and extracting the recognition data from sample components. During the recognition phase comparison of various component parameters takes place between taught and viewed items, this data is used to calculate recognition and orientation. Recognition is requested by the robot, carried out by high speed assembly sections and results are sent directly to the robot without intervention from the user.

The final system, consisting of 43 K bytes of program, was tested with a series of components designed to analyse the systems' effectiveness. Recognition was very good, at almost 100% success, with the correct models selected. Accuracies of better than  $\pm 1$  pixel, or  $\pm 1$  in 256 and better than 1 degree were attained. The time taken for recognition varies between 0.2 and 0.9 of a second dependant upon the number of components and the models selected. The cost of components for the complete system was approximately £400.

The system does however have some limitations which may affect its use in certain applications. These limitations are mainly due to the systems' requirement for contrasting, planar non-overlapping images to be presented within the field of view. Despite these limitations, some of which have partial solutions, it is felt that a usable robot vision system has been developed, built and tested.



## 2.0 Introduction.

With the growing cost of human resources and the pressing need for increased productivity, industry is turning more and more towards automation, specifically the use of robots. Exactly what is a robot? The word itself comes from the Czech word robota, meaning work, the Oxford dictionary defines it as "apparently human automation, intelligent and obedient but impersonal machine." However, with that description, even a washing machine can be considered a robot. The British Robotic Association gives a more precise definition and introduces some key concepts:

" A reprogrammable device designed to both manipulate and transport parts, tools, or specialised manufacturing implements through variable programmed motions for the performance of specific manufacturing tasks. "

In short, a robot is a re-programmable, general purpose manipulator with external sensors that enable it to perceive and recognise its environment and to perform assembly tasks. As such, it must possess some "intelligence," which is normally due to the computer unit associated with its control system.

The word "robot" first entered the English language in 1922 when Karel Carpek, a Czechoslovakian philosopher and playwright, presented his most successful stage effort, "R.U.R." or "Rossum's Universal Robots." Old man Rossum and his son discovered a chemical composition that simulated protoplasm. They elected to organise it in the form of man and, they fondly hoped, in the service of man. Young Rossum said,

"It's absurd to spend twenty years making a man. If you can't make him quicker than nature, you might as well shut up shop." The practical engineer Rossum overhauled the basic design to eliminate superfluous organs, dimensions, senses and especially a soul. Rossum opined, "A man is something that feels happy, plays the piano, likes going for walks, and, in fact, wants to do a whole lot of things that are really unnecessary....But a working machine must not play the piano, must not feel happy, must not do a whole lot of other things. Everything that doesn't contribute directly to the progress of work should be eliminated.

The next mention of robots came in the 1940's when Issac Asimov, the science fiction writer, envisaged robots in the service of man. Asimov's robots were kind, not being able to harm man or fellow machine. The final step came in the late 1950's when Joseph F. Engelberger, founder and president of Unimation Inc., developed and sold the first commercial industrial robots. Since then, only sixty two years after Carpek's prognostication, there have been considerable developments in the manufacturing industry, lighter and stronger materials, large use of integrated circuits and computers and a greater numbers of continuous production lines to name but a few. These changes have lead to the development and production of robots on a large scale, there currently being over one hundred types of commercially produced unit.

The type of robot we are concerned with in this thesis is the practical industrial robot described above, not the humanoid type depicted in the cinema and science fiction. This type does exist but is primarily for shows and does very little work. Indeed, the industrial robot is merely a simulation of a human arm, which when