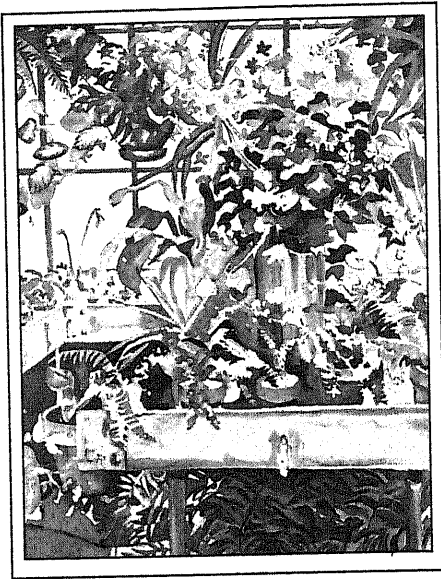


David Vernon

MACHINE VISION

*Automated Visual Inspection
and Robot Vision*

Machine Vision



FROM THE BOOKS OF

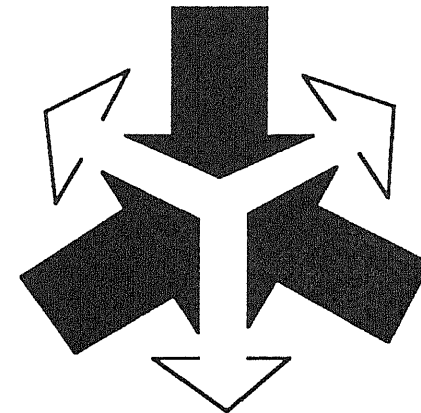
Robert FISHER

Machine Vision

*Automated Visual
Inspection and
Robot Vision*

David Vernon

*Department of Computer Science
Trinity College Dublin Ireland*



Prentice Hall

New York London Toronto Sydney Tokyo Singapore



First published 1991 by
Prentice Hall International (UK) Ltd
66 Wood Lane End, Hemel Hempstead
Hertfordshire HP2 4RG
A division of
Simon & Schuster International Group

© Prentice Hall International (UK) Ltd, 1991

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form, or by any means, electronic, mechanical, photocopying, recording or otherwise, without prior permission, in writing, from the publisher.
For permission within the United States of America contact Prentice Hall Inc., Englewood Cliffs, NJ 07632.

Typeset in 10 on 12 point Times
by MCS Typesetters, Salisbury, Wiltshire, England

Printed and bound in Great Britain
by Cambridge University Press

Library of Congress Cataloging-in-Publication Data
is available from the publisher

British Library Cataloguing in Publication Data

Vernon, David
Machine vision.
I. Title
006.3

ISBN 0-13-543398-3

1 2 3 4 5 95 94 93 92 91

*Everything that I can spy
Through the circle of my eye,
Everything that I can see
Has been woven out of me;
I have sown the stars, and threw
Clouds of morning and of eve
Up into the vacant blue;
Everything that I perceive,
Sun and sea and mountain high,
All are moulded by my eye:
Closing it, what shall I find?
– Darkness and a little wind.*

James Stephens
The Hill of Vision

Contents

<i>Preface</i>	xi
<i>Acknowledgements</i>	xiii
1 An introduction to computer vision	1
1.1 Computer vision: image processing or artificial intelligence?	1
1.2 Industrial machine vision vs. image understanding	3
1.3 Sensory feedback for manufacturing systems: why vision?	4
1.4 Examples of industrial machine vision problems and solutions	6
1.4.1 <i>Measurement of steel bars</i>	7
1.4.2 <i>Inspection of computer screens</i>	8
1.5 A typical system architecture	9
2 Illumination and sensors	15
2.1 Illumination	15
2.2 Sensors	17
2.2.1 <i>Image formation: elementary optics</i>	17
2.2.2 <i>Camera sensors</i>	19
2.2.3 <i>Camera interfaces and video standards</i>	22
2.2.4 <i>Characteristics of camera sensors</i>	23
2.2.5 <i>Commercially available cameras</i>	27
3 Image acquisition and representation	28
3.1 Sampling and quantization	28
3.1.1 <i>Spatial frequency and the effects of sampling</i>	29
3.2 Inter-pixel distances	34
3.3 Adjacency conventions	35
3.4 Image acquisition hardware	37
3.5 Speed considerations	41

4	Fundamentals of digital image processing	44
4.1	Point operations	45
4.1.1	<i>Contrast stretching</i>	46
4.1.2	<i>Thresholding</i>	49
4.1.3	<i>Noise suppression by image addition</i>	51
4.1.4	<i>Background subtraction</i>	52
4.2	Neighbourhood operations	53
4.2.1	<i>Convolution</i>	53
4.2.2	<i>Noise suppression</i>	56
4.2.3	<i>Thinning, erosion, and dilation</i>	61
4.3	Geometric operations	67
4.3.1	<i>Spatial warping</i>	67
4.3.1.1	<i>The spatial transformation</i>	69
4.3.1.2	<i>Grey-level interpolation</i>	71
4.3.2	<i>Registration and geometric decalibration</i>	74
4.4	Mathematical morphology	74
4.4.1	<i>Basic set theory</i>	74
4.4.2	<i>Structuring elements and hit or miss transformations</i>	75
4.4.3	<i>Erosion and dilation</i>	76
4.4.4	<i>Opening and closing</i>	78
4.4.5	<i>Thinning and the extraction of endpoints</i>	79
4.4.6	<i>Application: identification of endpoints of electrical wires</i>	80
4.4.7	<i>A brief introduction to grey-scale mathematical morphology</i>	80
5	The segmentation problem	85
5.1	Introduction: region- and boundary-based approaches	85
5.2	Thresholding	86
5.2.1	<i>Global, local, and dynamic approaches</i>	87
5.2.2	<i>Threshold selection</i>	87
5.3	An overview of edge detection techniques	90
5.3.1	<i>Gradient- and difference-based operators</i>	92
5.3.2	<i>Template matching</i>	99
5.3.3	<i>Edge fitting</i>	103
5.3.4	<i>Statistical techniques</i>	105
5.3.5	<i>Assessment of edge detection</i>	106
5.4	Region growing	106
5.4.1	<i>The split and merge procedure using quad-trees</i>	107
5.5	Boundary detection	108
5.5.1	<i>Boundary refining</i>	109
5.5.2	<i>Graph-theoretic techniques</i>	109
5.5.3	<i>Dynamic programming</i>	110
5.5.4	<i>Contour following</i>	110

6	Image analysis	118
6.1	Introduction: inspection, location, and identification	118
6.2	Template matching	119
6.2.1	<i>Measures of similarity</i>	119
6.2.2	<i>Local template matching</i>	121
6.3	Decision-theoretic approaches	122
6.3.1	<i>Components of statistical pattern recognition process</i>	122
6.3.2	<i>Simple feature extraction</i>	123
6.3.3	<i>Classification</i>	124
6.3.3.1	<i>A synopsis of classification using Bayes' rule</i>	126
6.4	The Hough transform	130
6.4.1	<i>Hough transform for line detection and circle detection</i>	130
6.4.2	<i>The generalized Hough transform</i>	134
6.5	Histogram analysis	136
7	An overview of techniques for shape description	140
7.1	A taxonomy of shape descriptors	141
7.2	External scalar transform descriptors: features of the boundary	141
7.3	Internal scalar transform descriptors: features of the region	143
7.4	External space domain descriptors: spatial organization of the boundary	145
7.4.1	<i>An algorithm for resampling the boundary chain codes</i>	148
7.5	Internal space domain descriptors: spatial organization of the region	150
8	Robot programming and robot vision	156
8.1	A brief review of robot programming methodologies	157
8.2	Description of object pose with homogeneous transformations	158
8.3	Robot programming: a wire crimping task specification	164
8.4	A simple robot-programming language	181
8.5	Two vision algorithms for identifying ends of wires	189
8.5.1	<i>A binary vision algorithm</i>	189
8.5.2	<i>A grey-scale vision algorithm</i>	192
8.5.3	<i>The vision/manipulator interface</i>	195
8.6	The camera model and the inverse perspective transformation	196
8.6.1	<i>The camera model</i>	197
8.6.2	<i>The inverse perspective transformation</i>	200
8.6.3	<i>Recovery of the third dimension</i>	202
8.7	Three-dimensional vision using structured light	203

9 Introduction to image understanding	211
9.1 Representations and information processing: from images to object models	211
9.2 Organization of visual processes	212
9.3 Visual representations	214
9.3.1 <i>The raw primal sketch</i>	214
9.3.2 <i>The full primal sketch</i>	215
9.3.3 <i>The two-and-a-half-dimensional sketch</i>	221
9.3.4 <i>Three-dimensional models</i>	224
9.3.4.1 <i>Volumetric representations</i>	224
9.3.4.2 <i>Skeletal representations</i>	225
9.3.4.3 <i>Surface representations</i>	226
9.3.5 <i>The extended Gaussian image</i>	228
9.4 Visual processes	230
9.4.1 <i>Stereopsis</i>	230
9.4.2 <i>Camera motion</i>	231
9.4.3 <i>Shading</i>	243
9.5 Concluding remarks	248
<i>Appendix: Separability of the Laplacian of Gaussian Operator</i>	253
Index	255

Preface

Machine vision is a multi-disciplinary subject, utilizing techniques drawn from optics, electronics, mechanical engineering, computer science, and artificial intelligence. This book is intended to be an in-depth introduction to Machine Vision which will allow the reader quickly to assimilate and comprehend the essentials of this evolving and fascinating topic. Significant emphasis will be placed on providing the reader with a solid grounding in the fundamental tools for image acquisition, processing, and analysis; a range of techniques, dealing with very simple two-dimensional systems, through more sophisticated robust two-dimensional approaches, to the current state of the art in three-dimensional robot vision, will be explained in some detail. Both application areas of automated visual inspection and robot vision are addressed. Recognizing that machine vision is just a component of a larger automation system, a brief introduction to robot programming will be provided, together with an explanation of the mechanisms by which robot vision modules interact with the programming language. It is important to recognize that the discipline of machine vision is presently undergoing a maturing process, with sophisticated techniques drawn from current research being exploited more and more in industrial systems. Without doubt, there is a long way to go, but the die is well cast. Acknowledging this trend, the last chapter of the book is devoted to the more research-orientated topics of three-dimensional image understanding and early visual processing (e.g. stereopsis and visual motion). It would indeed be foolhardy to attempt an exhaustive treatment of these areas; each deserves a volume on its own. However, if the essence of the philosophy of robot vision in its broadest sense is cogently imparted to the reader, then the exercise will have been successful and worth while.

The book is directed at final-year undergraduate and first-year graduate students in computer science and engineering, and at practising industrial engineers; the fundamental philosophy being to impart sufficient knowledge so that the reader will be competent to begin the implementation of a simple vision system and to enable him/her to study each issue independently in more depth. To that end, care

is taken to provide adequate references to supporting texts, reports, and research papers. In this way the book may be viewed both as a self-contained introductory text and as a spring-board to more detailed and specific study.

Acknowledgements

Special thanks are due to Kenneth Dawson of the Computer Vision Group, Department of Computer Sciences, Trinity College, Dublin, for his work on the raw primal sketch, the extended Gaussian image, and the polyhedral models; and to Massimo Tistarelli and Prof. Giulio Sandini at the University of Genoa for their help with the examples of camera motion and stereopsis. Many people in the Trinity Computer Vision Group read draft versions of this book and I am grateful for their contributions. I would also like to record a note of thanks to Dr R. Dixon, The University, Manchester, for his many valuable comments on an earlier draft of this book. Several of the examples in this book were facilitated by research funded by the Commission of the European Communities under the European Strategic Programme for Research and Development in Information Technology: Project 419 – Image and Movement Understanding.