Robot Sensors

Volume 1
Vision

Edited by:
Alan Pugh

IFS (Publications) Ltd, UK
Springer-Verlag
Berlin · Heidelberg · New York · Tokyo
1986

International Trends in Manufacturing Technology

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British Library Cataloguing in Publication Data

Robot sensors.—(International trends in manufacturing technology)
Vol. 1 : Vision
1. Robots 2. Pattern recognition systems
I. Pugh, A. II. Series
629.8'92 TJ211

ISBN 0-948507-01-2 IFS (Publications) Ltd
ISBN 3-540-16125-2 Springer-Verlag Berlin Heidelberg New York Tokyo
ISBN 0-387-16125-2 Springer-Verlag New York Heidelberg Berlin Tokyo

Phototypeset by Wagstaffs Typeshuttle, Henlow, Bedfordshire
Printed and bound by Short Run Press Ltd, Exeter

Robot Sensors

International Trends in Manufacturing Technology

The advent of microprocessor controls and robotics is rapidly changing the face of manufacturing throughout the world. Large and small companies alike are adopting these new methods to improve the efficiency of their operations. Researchers are constantly probing to provide even more advanced technologies suitable for application to manufacturing. In response to these advances IFS (Publications) Ltd is publishing a series of books on topics that highlight the developments taking place in manufacturing technology. The series aims to be informative and educational.

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The series is intended for manufacturing managers, production engineers and those working on research into advance manufacturing methods. Each book will be published in hard cover and will be edited by a specialist in the particular fields.

This, the sixth in the series – Robot Sensors, Vol. 1 – is under the editorship of Professor Alan Pugh of the University of Hull, UK. The series editors are: Michael Innes, John Mortimer, Brian Rooks, Jack Hollingum and Anna Kochan.

Finally, I express my gratitude to the authors whose works appear in this publication.

John Mortimer,
Managing Director,
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Acknowledgements

IFS (Publications) Ltd wishes to express its acknowledgement and appreciation to the following publishers/organisations for granting permission to use some of the papers reprinted within this book.

IFS (Conferences) Ltd
35-39 High Street
Kempston
Bedford MK42 7BT
England

John Wiley and Sons, Inc.
605 Third Avenue
New York, NY 10158
USA

GEC Research Laboratories
Marconi Research Centre
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Chelmsford
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England

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Redcliffe Way
Bristol BS1 6NX
England

National Research Council of Canada
Montreal Road
Ottawa
Ontario K1A OR8
Canada

Plenum Press
227 West 17th Street
New York, NY 10011
USA

National Science Foundation
1800 G Street North-west
Washington, DC
USA

General Motors Research Laboratories
Warren, MI 48090-9055
USA

Preface

Robot sensors have been the subject of much research in recent years; indeed two volumes are required to present adequately the quantity of individually published work in this area. This first volume covers aspects of 'vision'. It is naively assumed that sensors for robot vision applications are in plentiful supply. This implies that cameras, designed for television applications, are acceptable for use in robotic applications but experience shows that these products need extensive modification to tolerate the rugged environment of a robotic workcell. In fact this book on vision sensors makes little reference to conventional solid-state commercial television cameras. Indeed, it is not an exaggeration to claim that there is a crisis surrounding the robot sensor market even though much published research relies on the assumption that 'the sensor' is forthcoming. When attempts are made to apply the results of research in industry the realisation that the sensor needed is just not available completely defeats the objective.

Although, curiously, little has been written on the subject of vision sensors, this book is representative of the most notable developments in the field. Readers might be surprised to find that Volume 2, dealing with 'non-vision sensors', reveals much more activity in terms of research and some results in terms of commercial exploitation. *The two volumes should be used together* to provide a comprehensive collection of papers representing both historical developments and recent ideas from authors who have published in this area.

In this volume, the first section includes a review of the sensor issue presented by the editor earlier this year. This is supported by a detailed paper evaluating the principles of imaging sensors which are exploited in the manufacture of commercial television cameras. The second section identifies an area which should be substantially larger than it is in dealing with such an important topic as 'special vision sensors'. Much more is needed in this area to satisfy the thirst for sensor applications in robotic workcells.

Fibre-optics plays an important part in robot vision and this is covered by a selection of papers in the third section. In the same way, the importance of laser technology in the design of sensors is covered in the fourth section.

A topic which is sometimes (conveniently) forgotten is that of scene illumination, including structured light. It cannot be stressed too strongly how important it is to control the illumination of the work area through the sense of innovative lighting techniques and, where possible, the use of structured light in the form of a 'light stripe'; this is the subject of section five.

It is the intention of the editor and the publisher to provide an easily accessible treatment of this crucial technology in anticipation that effort will be focused on providing commercial products more readily acceptable in robotic applications.

Professor Alan Pugh
University of Hull, UK

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Reviews

The two papers in this section set the scene for robot sensors in general and imaging sensors in particular.

ROBOT SENSORS – A PERSONAL VIEW

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The current situation surrounding robot sensors is surveyed in the context of sensory requirements for robotics. Visual and tactile sensors are covered in some detail with the deficiencies in existing sensory methods highlighted. The paper justifies the claim that there are very few sensors available which are designed specifically for robotic applications. In particular, it is often assumed that vision sensors are freely available, but the opposite is indeed the case.

What is the present situation in robotics? We see considerable maturity in the design and manufacture of the robot manipulator and in particular the evolution of new kinematic arrangements. Further, we see the acceptance of computer control systems to drive manipulators with a good initial attempt to introduce robot programming languages incorporating important interpolative functions. Consequently, it can be suggested that the mechanical manipulator coupled with its computer controller has reached a point of substantial development with virtual complete acceptance in a shop-floor environment.

Regrettably, environmental sensing is a different story. In parallel with the development of robotic technology, and possibly preceding it, we have a great understanding of computer vision invariably with applications in picture processing of one kind or another. It is assumed that there is natural integration of what has been researched and developed in computer vision with robotic technology but the marriage is an uneasy one. Indeed, a new industry is emerging from the specialised knowledge needed for the production of reliable sensory systems. Those involved in the application of environmental sensing to robotic installations rapidly understand the particular and peculiar requirements of the technology. Implementing real-time sensory feedback proves to be a difficult and challenging task requiring new thinking in the design of algorithms. And if this is not enough, the system builder does not have at his fingertips the availability of sensors which robotics demands despite the naive assumption that sensors – particularly vision sensors (the subject of this Volume) – are plentiful. It is against this background that the sensor crisis is explored here with an attempt to summarise the present position in terms of research and manufacture.

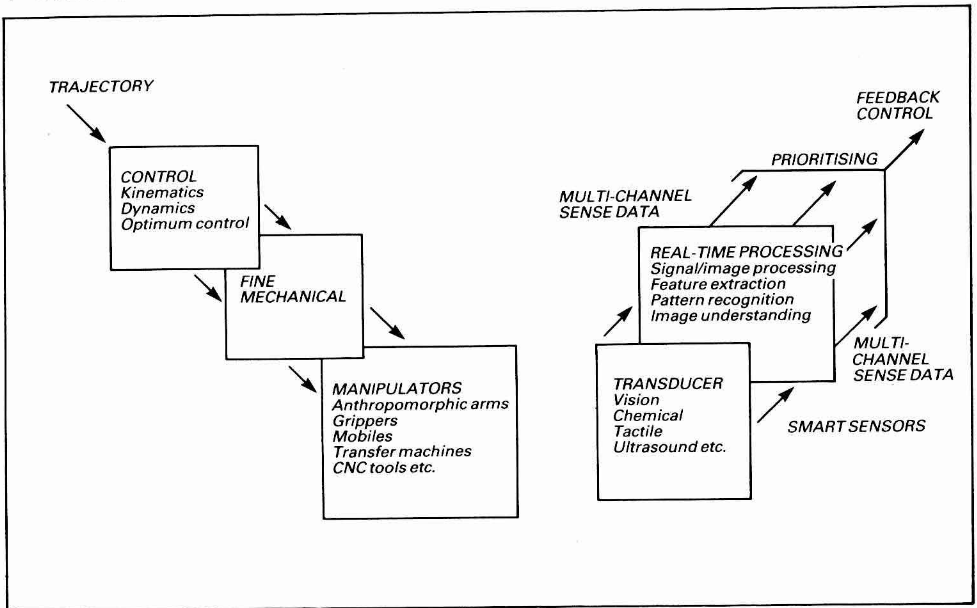

Fig. 1 The role of the manipulator and the sensor in robotics

To put the subject of robotics into context, Fig. 1 shows how robotics is seen through the eyes of the manipulator and alternatively through the eyes of the sensor. These diagrams give a clear pictorial description of these two aspects[1]. Davey completes the picture with a conceptual illustration of how the programmer might see the subject (Fig. 2) where the role of the sensor is clearly evident. This further underlines the crucial position occupied by the environmental sensor without which the total technology cannot be sustained.

Transducers available

The situation for vision transducers develops logically starting with the photodetector to determine presence (as realised in the proximity sensor) and progressively expanding the information collected through the linear array, which can be used either for range or one-dimensional transduction to the area array and television camera. These latter devices are perhaps most readily recognised as the fundamental transducers in vision systems. However, as we shall see later, there is more to this than meets the eye. The list for vision is completed by the recognition of the laser as an important tool in gathering three-dimensional information about the 'real world'. Whilst optical fibre is in itself not a transducer, it is a very powerful and important medium to communicate optical information away from a small volume.

The situation with tactile and force sensing is more confused. What is implied in force sensing is a measurement of pressure in the form of a moment about an axis or alternatively torsion concentric with an axis. When realised as a sensory wrist, the role of force sensing is readily apparent. Tactile sensing is better associated with tactile imaging when an attempt to replicate 'feel' through the construction of an array of tactile 'pressure

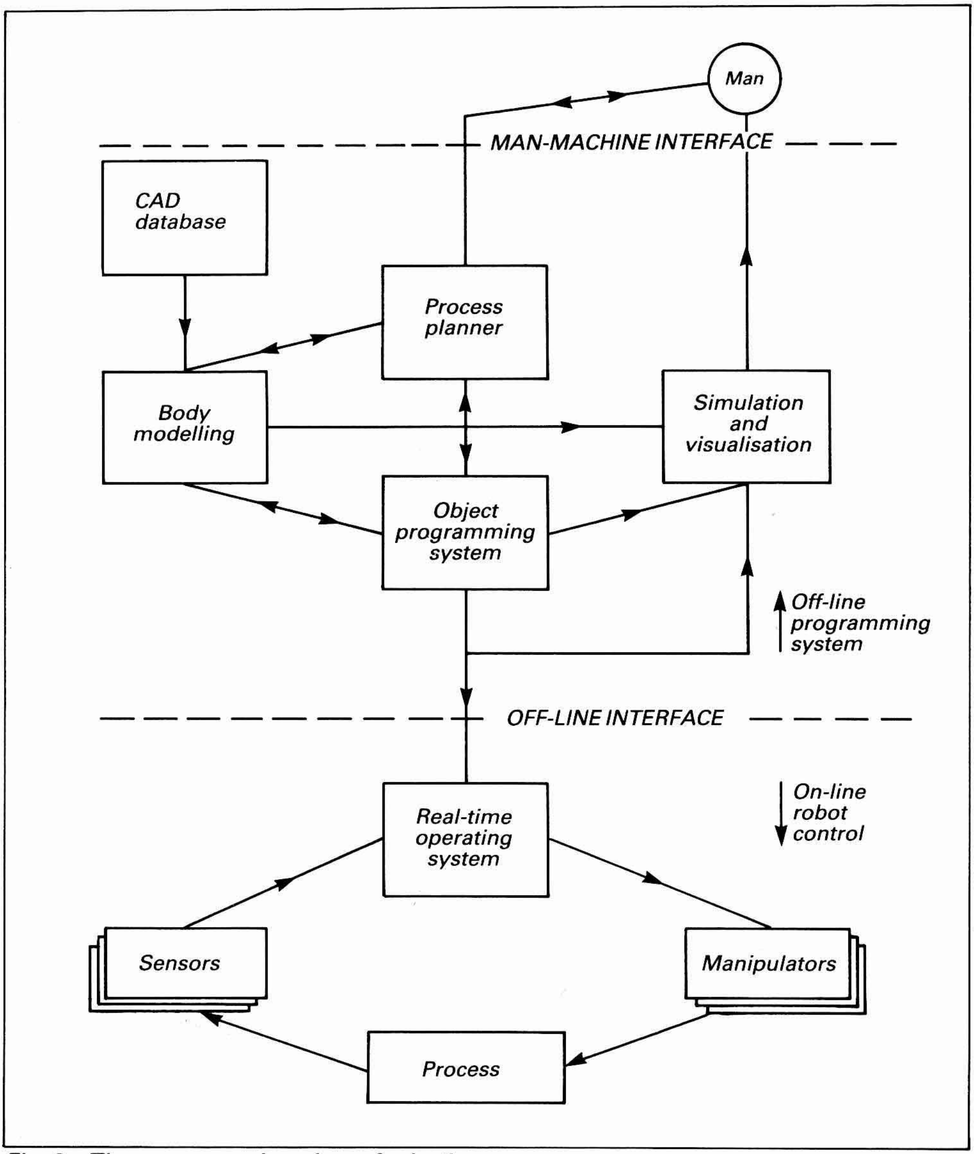

Fig. 2 The programming view of robotics

points' is used to construct shape information through touch. This latter class of sensors has resulted in some very interesting work but has barely reached commercial exploitation.

Acoustic transducers have a useful although specialised role to play in robotics. The promise of acoustic imaging is attractive – particularly for free-roving robots. This is a singularly difficult area in which to practice research and results are only now beginning to emerge from early experiments in this area. Apart from the use of microphones for voice control of robotic systems, they can for example be used to listen to characteristic noises emitted during the act of assembly[2].

Of course, a variety of other sensors might find application in robotics. Already, there is an example of the use of chemical sensing[3] although in this illustration the information extracted is not being used to guide the robot. The use of thermal imaging might have attractions if components can be heated or cooled relative to the ambient temperature and so enhance their 'visual' contrast. In the same way, ionising radiation might be used to enhance component shape. Indeed, the whole problem of scene illumination will be explored later.

Having taken a first look at the transduction principle available for sensors each sector will now be explored in turn in greater detail.

Vision sensors

Some misconceptions

It is generally believed that vision sensors are readily available to support robotics. The truth of the matter is that vision sensors are often confused with electronic cameras designed primarily for the television industry. Indeed, it must be stated, to avoid any misunderstanding, that there are virtually no vision sensors specifically manufactured for robotic applications! Having realised this fact, the robotic industry is in a dilemma in having the transducers available (through self-scanned imaging arrays) but having no cameras specifically designed for the robotic environment.

Again, the location of a vision sensor in the work area is frequently poorly implemented through a combination of the lack of suitable vision sensors coupled with an attempt to replicate the distribution of vision sensing in much the same way as the human form. All too often robot vision is incorporated by placing a solid-state camera above the work area just as our own eyes look down on the task implemented by our hands. It is of fundamental importance to understand that sensors must be distributed around the work area including the robot manipulator. By placing of a vision sensor on the end-effector of the robot, the problems of: parallax, coordinate transformation and resolution are greatly simplified.

Let us explore each of these in turn. A three-dimensional object when viewed as a two-dimensional profile will reveal a variation in perimeter size according to the angle of view[4]. The true profile shape of such a three-dimensional object can only be determined when the camera is placed immediately above its centre. With a camera placed on the end-effector, both the gripper and the camera are servoed to the centre line of the object and any parallax error first determined is eliminated through an iterative process as the end-effector approaches the centre-line.

Coordinate transformation between vision and robot axes is required whenever vision sensors are incorporated. Should the two be separated in space, the problem of coordinate transformation is considerable and the computational implications of the transformation matrix are well understood. However, all this presupposes that the calibration of both the manipulator and vision sensor can be maintained and sustained over a period of time. In a working environment this cannot be assumed. The expedient of placing the vision sensor on the end-effector reduces the problem of coordinate transformation to triviality and the physical separation of the mechanical gripper and the environmental sensor is determined by the dimension of the fixing bracket. Calibration is also far less critical with this form of implementation.

The popular belief that resolution should be as high as possible can only be sustained when the vision sensor is mounted remotely. It is very revealing to see how a low resolution sensor mounted on the end-effector can out-perform a much higher resolution camera mounted above the work area[5]. One of the earliest attempts to integrate properly the vision sensor with the robot gripper was published by the University of Nottingham[6]. The significance of this kind of thinking is not always understood – even after more than a decade of research and development.

Rebuilt cameras

The most elegant attempts to incorporate vision sensing in a robotic system are achieved by integrating a purpose-built camera with the robot end-effector. The best recent example arises from work at Oxford University[7] (see page 255). Such an approach is often implemented by taking an already manufactured solid-state camera and dismantling it to a point when it can be repackaged in a more robust structure. The Oxford welding head (manufactured by Meta Machines, UK) is enhanced by the knowledge that the working environment of the CCD array camera is dominated by a welding arc a mere 10cm away. Incidentally, this product also contains a laser light-stripe source of illumination which is discussed in the next section.

Another example of a repackaged camera has been published by the RCA Laboratories[8] (see page 85) on the design of an end-effector to handle loudspeaker assemblies. Incidentally, this particular end-effector also incorporates force feedback measured by the deflection of compliant beams. In looking at these two examples it would be natural to conclude that scope exists for a 'dismantled' camera system to be marketed for housing within custom-built end-effectors. This has an exact parallel in the availability of frameless dc motors commonly used as actuators in robot manipulators.

Some experiments on special vision sensors

Whilst special robotic vision sensors have not been made commercially in any quantity, a number of interesting experiments – sometimes conceptual – have been published. For example the very simple arrangement of a discrete array of parallel light beams shining across the space between gripper fingers has been investigated by the Bell Laboratories[9] (see page 139). When this simple arrangement of a relatively small number of light beams is integrated with the manipulating capability of the robot end-effector, useful information can be acquired about the components being handled. It should not be assumed that the relatively limited resolution implied by a few light beams dominates the resolving power of the total system. When combined with the fine positioning capability of a given manipulator, it is this resolution which also has an effect on the overall accuracy of the vision sensor. This is an extension of the optical proximity sensor and illustrates beautifully the concept of simple sensors used intelligently to present positional data to the robot controller.