ROBOT CONTROL

Theory and applications

Edited by

K. Warwick and A. Pugh

Peter Peregrinus Ltd on behalf of the Institution of Electrical Engineers

Published by: Peter Peregrinus Ltd., London, United Kingdom

ISBN 0 86341 128 2

Printed in England by Short Run Press Ltd., Exeter

IEE CONTROL ENGINEERING SERIES 36

Series Editors: Prof. D. P. Atherton
Dr K. Warwick

ROBOT CONTROL

Theory and applications

Other volumes in this series

Volume 1 **Multivariable control theory** J. M. Layton
Volume 2 **Elevator traffic analysis, design and control** G. C. Barney and S. M. Dos Santos
Volume 3 **Transducers in digital systems** G. A. Woolvet
Volume 4 **Supervisory remote control systems** R. E. Young
Volume 5 **Structure of interconnected systems** H. Nicholson
Volume 6 **Power system control** M. J. H. Sterling
Volume 7 **Feedback and multivariable systems** D. H. Owens
Volume 8 **A history of control engineering, 1800-1930** S. Bennett
Volume 9 **Modern approaches to control system design** N. Munro (Editor)
Volume 10 **Control of time delay systems** J. E. Marshall
Volume 11 **Biological systems, modelling and control** D. A. Linkens
Volume 12 **Modelling of dynamical systems—1** H. Nicholson (Editor)
Volume 13 **Modelling of dynamical systems—2** H. Nicholson (Editor)
Volume 14 **Optimal relay and saturating control system synthesis** E. P. Ryan
Volume 15 **Self-tuning and adaptive control: theory and application** C. J. Harris and S. A. Billings (Editors)
Volume 16 **Systems modelling and optimisation** P. Nash
Volume 17 **Control in hazardous environments** R. E. Young
Volume 18 **Applied control theory** J. R. Leigh
Volume 19 **Stepping motors: a guide to modern theory and practice** P. P. Acarnley
Volume 20 **Design of modern control systems** D. J. Bell, P. A. Cook and N. Munro (Editors)
Volume 21 **Computer control of industrial processes** S. Bennett and D. A. Linkens (Editors)
Volume 22 **Digital signal processing** N. B. Jones (Editor)
Volume 23 **Robotic technology** A. Pugh (Editor)
Volume 24 **Real-time computer control** S. Bennett and D. A. Linkens (Editors)
Volume 25 **Nonlinear system design** S. A. Billings, J. O. Gray and D. H. Owens (Editors)
Volume 26 **Measurement and instrumentation for control** M. G. Mylroi and G. Calvert (Editors)
Volume 27 **Process dynamics estimation and control** A. Johnson
Volume 28 **Robots and automated manufacture** J. Billingsley (Editor)
Volume 29 **Industrial digital control systems** K. Warwick and D. Rees (Editors)
Volume 30 **Electromagnetic suspension—dynamics and control** P. K. Sinha
Volume 31 **Modelling and control of fermentation processes** J. R. Leigh (Editor)
Volume 32 **Multivariable control for industrial applications** J. O'Reilly (Editor)
Volume 33 **Temperature measurement and control** J. R. Leigh
Volume 34 **Singular perturbation methodology in control systems** D. S. Naidu
Volume 35 **Implementation of self-tuning controllers** K. Warwick (Editor)

List of authors

1 P. Adl and R.T. Rakowski; Brunel University, U.K.

2 P.C. Wong, M.T. Thorn and S, Littlewood; Hunddersfield Polytechnic, U.K.

3 S.A. Carr and M.J. Grimble; University of Strathclyde, U.K.
G. Anderson and J.V. Ringwood; National Institute for Higher Education, Dublin.

4 M. Farsi and K.J. Zachariah; University of Newcastle upon Tyne, U.K.
K. Warwick; University of Warwick, U.K.

5 J.Z. Sasiadek and R. Srinivasan; Carleton University, Canada.

6 Z. Taha; University of Malaya, Malaysia.

7 A. De Luca, P. Lucibello and F. Nicolò; Università di Roma, Italy.

8 A.Y. Zomaya and A.S. Morris; University of Sheffield, U.K.

9 M. Dickinson; Sheffield City Polytechnic, U.K.
A.S. Morris; University of Sheffield, U.K.

10 S.R. Pandian, M. Hanmandlu and M. Gopal; Indian Institute of Technology, New Delhi, India.

11 S.N. Ahmad and K. Natarajan; Nuclear Power Corporation, Bombay, India.

12 K. Ninomiya, I. Nakatani, J. Kawaguchi and K. Harima; Institute of Space and Astronautical Science, Tokyo, Japan.
K. Tsuchiya, M. Inoue and K. Yamada; Mitsubishi Electric Corporation, Hyogo, Japan

14 J. Pu and R.H. Weston; Loughborough University of Technology, U.K.

15 L.G. van Willigenburg; Delft University of Technology, The Netherlands.

16 P. Chiacchio and B. Siciliano; Università di Napoli, Italy

17 S. Engell and A. Kleiner; Fraunhofer Institut IITB Karlsruhe, Federal Republic and Germany.

18 W.M. Grimm, N. Becker and P.M. Frank; University of Duisberg, Federal Republic of Germany

19 P.C. Müller and J. Ackermann; University of Wuppertal, Federal Republic of Germany.

20 R.A. Basta, R. Mehrotra and M.R. Varanasi; University of South Florida, Tampa, U.S.A.

21 J.E. Sanguino, J.S. Mata, A.P. Abreu and J.J. Sentieiro; Technical University of Lisbon, Portugal.

22 R.M. Crowder; University of Southampton, U.K.

23 A. Ghanem; San Francisco State University, U.S.A.

24 J.E.E. Sharpe; Queen Mary College, London, U.K.

Preface

This book offers a cross-sectional view of recent research and development carried out in the field of robot control. In, what one may regard as, a fairly well defined topic area, a large number of diverse requirements are thrown together in order to achieve a particular aim. The methods by which that aim is realised depend on such as the type of robot, its workplace, the workpiece spectrum, sensing elements employed, programmed control algorithms, the hardware base and software selected. The papers in this volume are wide ranging in their coverage of the general robot control area and present an up-to-date picture of the subject.

The book contains edited papers, given at the IEE International Workshop on 'Robot Control: Theory and Applications', held at the University of Oxford in April 1988. The main objects of the meeting being to enable the presentation and discussion of recent research results and novel developments. The Workshop was therefore allowed to have a broad scope, and the selection procedure applied to the papers submitted was carried out with this in mind. When given, the papers were divided into themed sessions as can be seen from the Contents section, which allows for each session to be regarded separately if desired.

The integration of sensory information into an overall control scheme is a increasingly important aspect in the development of a systems approach to robot control, and this must enable reactions, possibly in real-time, to a varying environment or requirements. Both tactile and vision sensing elements are considered in this text. Further, the controllers employed at each level must be able to quickly adapt to these changes such that appropriate commands can be efficiently issued. Various adaptive schemes are discussed, including self-tuning, model reference and variable structure techniques.

Response modelling is of primary importance in formulating and assessing suitable control strategies, such as those necessary for the close control requirements of manipulator trajectory tracking. Several aspects of modelling are considered and the means by which tracking can be carried out are shown in terms of links formed with parameter estimation schemes, as those employed within adaptive controllers.

A selection of manipulator implementation results are covered, ranging from direct usage in nuclear power plants, through space manipulators and walking robots, to high speed applications which necessitate fast sampling rates. The important topic of Robust Control is also discussed. Robust Control methodologies have been of great prominence in the control systems research arena over the last few years, and some of the results, which have been obtained, are shown, via several papers, to contribute particularly to robot control. The combined papers on this subject area provide an excellent overview of robust controller design, within the context of robot manipulators.

The overall efficient control of manipulator performance can only be achieved when its working environment is also taken into account. This means that if more than one manipulator is being employed, the multi-manipulator operation should be coordinated. Environmental aspects, however, can also include human operatives in several guises, and stipulated performance objectives should take these points into account, as discussed in the final papers.

In conclusion, the editors would like to thank all of those who have helped both in the organisation of the Workshop and in the preparation of this book. Particular gratitude is extended to Andrew Wilson at the IEE for smoothly coordinating planning and operation of the Workshop, and to John Billingsley and Richard Weston for acting as session chairmen. At Peter Peregrinus Ltd, our thanks go to John St.Aubyn and Nick Bliss for enabling a quick turnaround from receipt of final copy to publication. Finally, a special thank you goes to Marie Jones who dealt excellently with the necessary modifications.

Kevin Warwick
Alan Pugh

January, 1988.

Contents

Chapter 1

Automatic compensation system for adaptive gripping using a magnetoresistive force and slip sensor

P. Adl and R. T. Rakowski

1. INTRODUCTION

Intelligent robots will need sensors that will give them artificial senses of sight and touch, and so be capable of adapting to their environment. Achieving such a goal will open up new application areas for robot technology not only in the traditional engineering sector but also in areas such as the food processing industry (1). Using cameras and pattern recognition programs in robotic applications is well advanced. However, with the problem concerning the sense of touch, the few systems developed have concentrated on concepts leading to devices which are not environmentally robust nor allow sufficient flexibility of application. Since most tasks in the area of gripping and placing can be achieved by responding to contact and force, it is desirable to instrument the gripper with force and touch sensors (2).

In practice the gripper is usually constructed as an open-loop control system and therefore the object can be badly damaged due to excessively strong gripping forces. Such an inconvenience cannot always be avoided by feedback control of the grasping force because it is not easy to specify its optimum value. In view of the recent trend towards the extensive use of industrial robots for handling objects of unknown (or varying) characteristics, it is very important to determine the optimum grasping force by some adaptive means so that objects are not damaged or dropped. One of the most effective means of controlling the grasping force is to use the feedback signal from slip detectors.

2. SENSOR REQUIREMENTS

2.1 Types and Tasks of Taction

In specifying the type of task to be performed two functions for the sensor can be described: to detect object shape and to measure the forces determining the motion of the object relative to the hand. Because these two functions are completely different it is possible to speak of two different types of tactile sensor: a 'shape' and a 'manipulative' one. It is easy to argue that most industrial manipulation is not concerned so much with the use of tactile sensing for object identification since it is almost invariably done better by optical means. Thus it seems that the primary role for a tactile sensor is a manipulative one, i.e., one that monitors the dynamics within the hand.

In the simplest possible case a robot has a manipulator with two fingers, having internal surfaces planar and parallel to each other. Objects grasped between the fingers can make point, line or plane contacts with these surfaces. The need for sensing arises when trying to carry out manipulative tasks. During manipulation within the fingers the object is temporarily out of equilibrium. Monitoring of the forces applied by the fingers at the points of contact are required. Assuming that the object remains always in contact with the fingers, it is possible to restrict attention to the position of the object confined between two fixed planes. The object then has three degrees of freedom; it can slide or slip parallel to the finger planes and can rotate about the axes perpendicular to them.

2.2 Tactile Technologies

Considerable effort has been directed at developing a workable tactile sensor - both in industry and in the academic community (3). Diverse approaches have been explored to develop tactile transducers with sensitivity and robustness using various physical effects. Most workers have different ideas on what kind of information can best be gained through taction and what to do with it once it has been gathered. However, shifting the emphasis from shape recognition to force monitoring eliminates many of the physical effects which appeared promising for shape tactile sensing. If the three dimensional force vector and associated couples are to be detected, then shear force sensing is vital. The limitation of measuring normal forces or pressures only rules out many tranduction technologies which have been proposed.

This limitation is primarily due to the nature of the transduction effect. In fact transduction is generally at the atomic level, where the transduction effect (e.g., piezo-resistive, strain gauge, piezo-electric, magneto-elastic, etc.) couples one form of energy to another. An inherent limitation of these 'microscopic' effects is the trade-off between sensitivity and fragility, and the restriction imposed by the design of the supporting structure on the direction of the forces that can be detected.

2.3 Using Magnetic Sensors for Force Detection

Of all the transduction techniques examined the only devices that have the capability of measuring the three dimensional force vector at numerous points in an array and be compact enough to be mounted on a robot gripper are certain magnetic field ones. Research work at Brunel (4) indicated that only Hall and Magnetoresistive effect devices have the ability to be fabricated in arrays, in small enough dimensions and compact enough to be implemented on a robot gripper. The magnetoresistive sensor, however, is more sensitive than Hall elements and can usually operate over a much wider temperature range. Moreover, its frequency range is much greater, since the magnetoresistive effect is not an inductive effect and can detect both d.c. and a.c. fields up to several megahertz. It is also a two terminal device and is not subjected to the many limitations inherent in a four-terminal Hall effect sensor.

3. MAGNETORESISTOR CHARACTERISTICS

3.1 Review

The magnetoresistive sensor is one of the more recent developments for detecting magnetic field variations (5). Magnetoresistive devices make use of a well known property of certain ferromagnetic materials such as permalloy (81% Ni and 19% Fe) to change resistivity in the presence of an external magnetic field. A thin, plannar single domain magnetoresistive film can be employed to sense a magnetic field to which it is exposed by passing an electrical sense current (either a.c. or d.c.) through the film, the films magnetisation vector being at an angle to the direction of current flow. The field being sensed exerts a torque on the magnetic moment in the film, causing the resistance of the film to increase or decrease depending on the sense and magnitude of the field applied to the film. The resistance of the film is therefore the analogue of the field strength. The exact theory of operation is well described by McGuire and Potter (6).

3.2 Fabrication

The cost of designing and manufacturing of magnetoresistive sensors for prototype devices is quite high. The method used for generating thin film patterns was to use evaporation masks. A suitably shaped aperture (referred to as a mask) has the desired pattern cut or etched into it. In a high vacuum chamber the mask is placed in close proximity to the glass substrate, thereby allowing condensation of the evaporant permalloy vapour only in the exposed substrate areas. The film thickness can be controlled by a rate monitor and a shutter.

Magnetoresistive sensors are the product of several evaporations. First a layer of Ni-Fe is deposited onto the substrate to form the permalloy element. This has to be done in the presence of a magnetic field aligned parallel to the plane of the film and in a direction related to the final magnetoresistive sensor geometry in order to provide a known magnetisation axis. Then, via a different set of masks, a layer of copper or gold is deposited at both ends of the element ot allow connection of the sensor to external circuits. Next an insulation layer, usually of photoresist is formed over the element and conductors to protect the

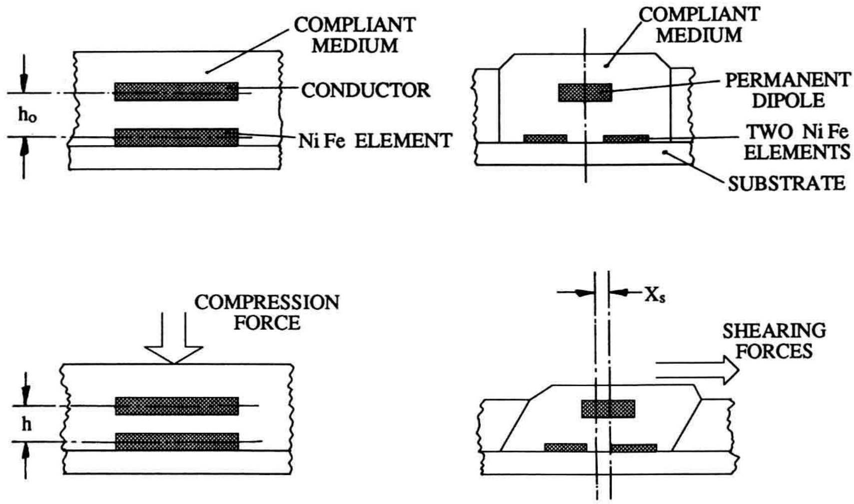

Fig.1. Normal and shear force detection

sensor during subsequent use.

The sensor characteristics can be finely controlled by altering the permalloy element geometry and configuration. The sensor configuration details which were designed specifically for this project cannot be revealed due to a patent protection application.

3.3 Force and Slip Detection

No matter how adaptable its control system, how large its memory, or how many articulations it possesses, the capability of the robot is ultimately determined by how well it handles objects. It must be able to grasp, lift, and manipulate workpieces without causing any damage and without letting go. Clearly the grasping surface of a robotic gripper will also be the sensing surface for the magnetoresistive force sensor. The forces exerted by the gripper on an object will deform a compliant medium and will thus displace a current carrying conductor or a magnetic dipole (Fig.1) with respect to the magnetoresistor. The magnetoresistor will detect a change in magnetic field and produce an electrical signal. This signal will be proportional to the distance the elastic medium has been deformed and hence represents the shear or compressive displacement forces.

The choice and design of the gripping surface is very critical. Tactile transducers must be wear-resistant; they should be able to withstand abuse, particularly in rugged industrial environments. Of course, specialised applications can require resistance to extreme conditions. However, most conventional positioning, assembly and inspection operations require no unusual durability or environmental resistance

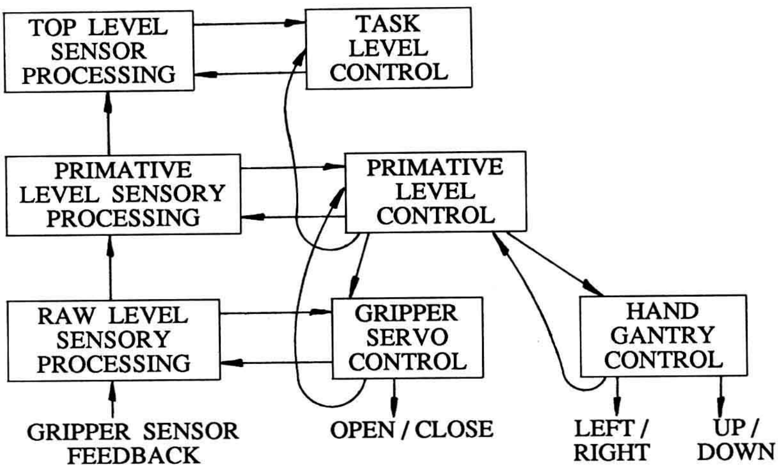

Fig.2. Hierarchical control for a basic adaptive gripper application.

(7). There are probably a large number of applications in which human hands may be directly replaced by automatic hands. Bearing in mind these considerations, natural rubber was chosen for the elastic medium offering a good balance of properties, in particular for its excellent mechanical characteristics.

The main conclusion that can be drawn from results to date is the excellent repeatability of the measured values. Undoubtably repeatability is a far more important factor than any other, even accuracy. For although accuracy is highly desirable, the primary requirement for indicating trends must be to produce a consistent result continuously.

Finally, what is the best distribution of these elements on a tactile sensor? To date grippers have always had to be customised and consequently tactile sensors will also need to be. Obviously, standardised devices and data processing packages are indispensable. General purpose design should reside mostly at the system level, while the touch sensors are specially configured for the application. To this end a modular design with linked sensing 'units' of either normal or shear force transducers could be used to construct the array. The optimum distribution of these units might then be resolved for different tasks by careful analysis of the application.