Robot Technology

Volume 3B: Teleoperation and Robotics

Robot Technology

A Series in Eight Volumes

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Volume 3B

TELEOPERATION AND ROBOTICS

Applications and Technology

Jean Vertut and Philippe Coiffet

Kogan Page
London

This work entitled *Teleoperation and Robotics* is published as two volumes:

Volume 3A *Evolution and Development*
Part 1 Introduction

Volume 3B *Applications and Technology*
Part 2 The contribution of computer science
Part 3 Performance and the man-machine interface
Part 4 Applications of teleoperation

The references cited in Volume 3A are placed after the text in Volume 3A, and the complete bibliography is included in Volume 3B. Both volumes are indexed separately. Whenever possible the figures are numbered consecutively according to the section in which they appear.

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First published 1985 by Hermes Publishing (France)
51 Rue Rennequin, 75017 Paris, France

English edition first published 1985
by Kogan Page Ltd, 120 Pentonville Road, London N1 9JN

British Library Cataloguing in Publication Data

Vertut, Jean
Teleoperations and robotics: applications and technology.— (Robot technology; 3B)
1. Robots
I. Title II. Coiffet, Philippe III. Series
629.8'92 TJ211

ISBN 978-94-011-6105-3 ISBN 978-94-011-6103-9 (eBook)
DOI 10.1007/978-94-011-6103-9

Robert Hartnoll (1985) ltd., Bodmin, Cornwall

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Publisher's note

It was shortly before going to press that we learnt of the death of Jean Vertut, the author of *Teleoperation and Robotics*. It is our hope that, in publishing these volumes, we have helped to provide a fitting tribute to his outstanding contribution to the field of teleoperation.

Foreword

It is a privilege to be asked to introduce this important work. Such a book has long been needed. Industrial manipulators and robots have caught the attention of the general public and become very fashionable in the last few years. The casual reader of current newspapers and magazines or the viewer of television and films might easily conclude that the development of mechanical hands, arms and legs or other mobility devices has progressed rapidly in only the last few years. Most people are unaware of the gradual orderly succession of creative designs and painstaking refinements which have been produced over a greater number of years.

That story is carefully described in this volume, together with diagrams and photographs which document in detail this elegant phase in the history of machine design. This volume together with Volume 3A constitute the most complete and comprehensive work on manipulators and teleoperators. Jean Vertut and Philippe Coiffet are well known not only as authors but also as engineers who have produced some of the finest devices in the world.

Of course for the complete history of manipulators and teleoperators one must look back to the artisans who crafted the delightful clockworks, mechanical puppets and toys before and during the Renaissance. However, the modern development of these devices was spurred most by the need which arose, concurrent with the development of nuclear power, to handle radioactive materials remotely. Unquestionably, 30 years ago the group at Argonne National Laboratory near Chicago headed by Ray Goertz led the field in mechanical design of manipulators. Shortly afterwards, in my judgement, world leadership swung to the CEA laboratory of Jean Vertut and during recent years the French School has set the pace – with intense competition from the Japanese and perhaps more recently the Americans.

The engineer or industrialist interested in automatic and computer-based machinery which is general purpose, ie which can be programmed to perform a great variety of tasks, should realize the close link with the design of machines to aid and extend the human hand for remote manipulation. This is not to ignore the mechanical design art in fixed automation which has accumulated since the industrial revolution.

It is only to appreciate the degree to which biomechanics and artificial mechanics interact to enrich understanding and catalyse new designs.

As we look ahead to designing manipulators, teleoperators and robots which integrate artificial sensors and intelligence with mechanical hands, arms and legs, it is important to keep in mind the lessons of man-machine symbiosis so elegantly presented in this work.

Thomas B. Sheridan
Professor of Engineering and Applied Psychology
Department of Mechanical Engineering
Massachusetts Institute of Technology
January 1985

Preface

This work is the result of 10 years of friendly and far-reaching co-operation between Philippe Coiffet and myself. This period represents a good third of the time I have devoted to remote handling and, more recently, robotics.

In addition to having been a member of the nuclear research community for some time and the influence of Ray Goertz, whom I met many times between 1962 and 1969, and his team on my work, I am also privileged to be involved in the study of work in all types of hostile environment, such as under water and outer space, aids to the handicapped, civil protection and industrial robotics. I share this privilege with Carl Flatau, who developed the use of teleoperation in particle accelerators, touched upon the use of teleoperation in outer space and in industrial robotics, and with whom I collaborated briefly at the time when our first electronic manipulator was developed. This study was productive for both parties.

A collaboration with Hans Kleinwachter, who made the transition from working in the field of outer space manipulation to working in the field of nuclear teleoperation during the Syntelman project, which remained at experimental level, was also productive. The innovators in the field of teleoperation are very small in number and include Ralph Mosher, who chaired the session when I delivered my first paper in the USA in 1962.

This liaison has led to my being involved in two scientific communities, both of which are featured largely in the bibliography of this work. The first body is the Remote System Technology Division (RSTD), which today forms part of the American Nuclear Society (ANS), and was originally established well in advance of the latter group by Ray Goertz in 1952. I have belonged to this community since 1962. The second body is the International Federation for Theory of Machines and Mechanisms (IFToMM), which France joined as late as 1979 in connection with its work on robotics. Since 1973 the IFToMM has organized, with the Centre International des Sciences Mécaniques (CISM), Udine, Italy, Robot and Manipulator Symposiums (RO.MAN.SY). These symposiums provide the only venue for world-wide exchange between roboticists, including mechanical engineers,

and those delegates from Eastern countries. *RO.MAN.SY Proceedings of the Fifth Symposium on Theory and Practice of Robots and Manipulators* Udine, Italy, June, 1984, edited by A. Morecki, G. Bianchi and K. Kedzior is available from Kogan Page.

Edwin G. Johnsen is another pioneer extensively quoted in the bibliography of this work, who, at the time of the American nuclear-powered rocket project NERVA, directed a team made up of representatives from NASA and the Atomic Energy Commission (AEC). He introduced the term *teleoperator* to mean a mobile telemanipulator which is not directly mechanically linked with the operator, whereas other terms such as *telechirics* (coined by M.W. Thring, Great Britain), *telemation* (used by Alexander, NASA, USA) and *telesymbiotics* (devised by Joel Charles, France) have not been so widely adopted.

Another new term, *telepresence*, is intended to describe sensory feedback, while the word *telesymbiotics* refers to the human operator, who is present (via the teleoperator) in the remote environment, and has these sensory, physical and decision making abilities. According to the authors, however, telepresence can function either unilaterally or bilaterally, and is therefore equivalent to telesymbiotics.

The importance of Edwin Johnsen's work remains undiminished, even after 15 years, which is why our reference to works published before 1967 are the ones he did not cite himself.

Over the last 10 years, I have also collaborated well with Joel Charles and the team at the Technical Direction for Naval Construction (DTCN), who have worked on developing the technology for work at depths of 6,000 m, built the first French Bathyscaphe, Archimede, and are currently involved with the CNEXO (now called IFREMER) SM97 submarine project. This was so named because 97 per cent of the sea bed is accessible at 6,000 m submergence.

My good friend Melvin Feldman is in charge of the nuclear telemaintenance team at Oak Ridge. This opens up new prospects for Franco-American exchange on advanced teleoperation. As a result of this, we both tried offering, in recent years, what help we could to colleagues at Three Mile Island, for whom teleoperation should provide a tremendous help in the recovery of their TMI-2 nuclear reactor, which has made slow progress since the 1979 accident.

As a result of a fascinating encounter with P. Rabischong, who introduced me to the field of biomechanics (which he defines as 'scientific espionage of living mechanical systems'), I discovered the Laboratory for Automation and Microprocessing, Montpellier (LAMM). This prompted the collaboration with Philippe Coiffet on the technology of (tele)manipulators and research into their control. This programme between an academic laboratory and a team from a large technical organization started over 10 years ago, and at the same time the friendship between my co-author and myself was founded, resulting today

in our awareness of and activity in the new field of service robotics.

At the time Edwin Johnsen's first works were appearing, our friend and colleague Michel Grenon published *Le travail en milieu hostile* (*Work in hostile environments*), which until now was the only book written in French on the subject (Grenon, 1968). More recently, our colleague W. Köhler (West Germany) produced an immense work containing all available information on existing telemanipulators, and his work is also frequently mentioned in the bibliography.

This work was devised by Philippe Coiffet and myself. Coiffet handled Part 2 on the contribution of computer science, a new aspect in teleoperation, as well as Chapter 3.1 on performance evaluation of teleoperation systems. Nicole Fiori and James Richardson of the Physiology of Movement Laboratory, Orsay Faculty, wrote Chapter 3.2 in Part 3, which concerns the human operator in relation to teleoperation systems. I wrote Parts 1 and 4. Part 1 is the entire text for Volume 3A and gives an introduction and account of the development of teleoperation. Part 4 describes a number of applications.

At a time when multidisciplinary analysis is being again adopted, after centuries of specialization, we have attempted to present a broad approach to the subject which, to a greater extent than many others, refuses to be restricted by an over-specialized approach. Therefore, in Part 4 I have summarized in terms of the different applications, the semi-historical progress of the preceding parts in terms of function, and suggested links between different areas of application. Although I may have succumbed to the temptation of writing at length on the subject of nuclear applications, this was in the hope of making them more widely known and helping to demystify this area as a whole, particularly in dispelling the impression that it is impossible to tackle dangerous situations involving nuclear materials by hand, which is entirely possible using remote handling techniques. Part 4 also cites the most recent work in the field.

I should like to thank all those without whom this work would not have been possible, the pioneers first of all, and in particular those who never had the opportunity to witness the possibilities opened up by advanced teleoperation, that is the advance from telemanipulation to teleoperation, and then to the wider context of robotics: my teachers and in particular André Leroi-Gourhan and Marcel Jousse (1965) who, in the fields of prehistory and anthropology taught me the importance of tackling problems directly and with a global approach (which is so difficult); next in chronological order, my closest collaborators J.-C. Germond, J. Le Tohic, R. Séran, J.-P. Guilbaud, P. Marchal, my close colleagues and friends P. Pesanti, G. Lefort, P. Auchapt, A. Crégut, J. Guittet, and more recently J.-L. Rouyer; outside the CEA P. Rabischong, J. Charles, P. Coiffet, A. Liégeois, A. Pardo, B. Espiau, S. Bouisset, J.-C. Guinot; in alphabetical order, in Germany,

H. Kleinwachter and W. Köhler; in the USA A. Bejczy, C. Flatau, J. Hill, B. McGhee, B. Roth, K. Salisbury, T. Sheridan, particularly M. Feldman, and the late J. Simon; in Japan, I. Kato; in Poland, A. Morecki; in the USSR, the late Artobolevski, and A. Bessonov; and finally, those working in industry producing products designed by the researchers: the late J.-C. Mettetal and C. Piron, in the USA; F. Chesley, D. Jelatis and particularly J.-P. Cazalis, whose team has been responsible for the production and distribution of much of my work.

It is not possible to mention all the members of the young team who are now working, under the direction of J.-L. Rouyer, P. Marchal and G. Fraize, with their friends in other teams on the subjects mentioned in this volume.

Finally, I should like to thank all those, at the CEA and elsewhere, who have contributed so much: P. Balligand, B. Jacquard, P. Tanguy, J. Pradel, and recently A. Milliés.

Jean Vertut
January 1985

The object behind Volumes 3A and 3B in the *Robot Technology* series is to show two aspects of a discipline called teleoperation, which until recently was not included in the field of robotics. It concerns the exploration and exploitation of spaces which because of their inaccessibility or hostility are generally forbidden to man. The first aspect covers the advances made in mastering teleoperation, using only a knowledge of mechanics. The second aspect concerns the more recent contribution of computer science and automatic control.

It was not until 1972, having written a thesis on another field of interest, particle accelerators, that I founded a research team into robotics at Montpellier. This same year I was introduced to teleoperation and met Jean Vertut, its driving force.

What struck me at the time was the extraordinary lack of communication between the world of industrial robotics for manufacturing systems (where automatic control is a basic necessity) and the world of nuclear teleoperation (in which man controls the system from a control station and mechanical solutions are investigated).

Working myself in the field of automatic control, the close collaboration with Jean Vertut, whose encyclopaedic knowledge of teleoperation is truly astonishing, was evidently very productive. This was enhanced by our solid friendship, and our common work well proved this point.

The problem with encyclopaedic knowledge is to turn it into a written account that reflects the genius behind it. This explains the rather lengthy process of completing the text, which started as a project of 200 to 300 pages, and has ended up as a two volume work running to more than twice the original length. However, this study is exhaustive, particularly concerning the history of the field.

The reader should be aware that in the last few years the approach adopted in industrial robotics (in which a simple task is automated first, then made more complex as the technology advances) and the approach used in teleoperation (in which complex tasks must be carried out, and technical advances have increased the efficiency with which the tasks are performed) tend to merge, so that in about 20 years' time, using in addition artificial intelligence techniques, near-perfect robots can be manufactured.

I should like to thank all the people with whom I have worked in this field, both at Montpellier and elsewhere, and in particular A. Liégeois, A. Fournier, B. Espiau, P. Marchal, M. Chirouze, E. Dombre, M.J. Aldon, R. Fournier, P. Rives, J. Pot, P. Kuspriyanto, R. Zapata, P. Dauchez, B. Jouvencel and S. Tobarghan.

Philippe Coiffet
January 1985